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VEHICLE AVERAGE USEFUL LIFE STUDY FOR TRUCK, 5 TON, 6X6, M39A2 SERIES

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An assessment of the useful life of Truck, 5 Ton, 6x6, M39A2 Series has been made. The M39A2 series trucks studied were the M52A2 Tractor, the M51A2 Cargo Truck and the M51A2 Dump Truck. Factors included in the study were: (1) cost of vehicle maintenance as a function of accumulated mileage and (2) performance of the vehicle (Reliability, Availability and Maintainability) as a function of

20. ABSTRACT (Cont'd)

accumulated mileage. It is shown that by an analysis of the cost and performance characteristics of the truck, the planned replacement life of the truck can be extended resulting in substantial cost savings to the Army.

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VEHICLE AVERAGE USEFUL LIFE STUDY FOR TRUCK, 5 TON, 6X6, M39A2 SERIES

1. SUMMARY

1.1 Problem.

To determine the age (mileage) at which it becomes economical to replace the M39A2 Series 5 Ton Truck with a new 5 Ton Truck.

1.2 Approach.

The useful life of the M39A2 Series 5 Ton Truck has been assessed by determining the mileage at which the average system cost per mile (costs associated with the acquisition, shipping and maintenance of the truck) is minimized (truck economic life). In addition, an evaluation of the truck's Reliability, Availability and Maintainability (RAM) performance characteristics over the economic life span was made to determine if the useful life of the truck should be less than the economic life because of RAM considerations. The M39A2 trucks included in the study were the M52A2 Tractor, M54A2 Cargo Truck and the M51A2 Dump Truck.

1.3 Discussion.

The study was based on the performance of 5,704 trucks reported in the Army Integrated Equipment Record Maintenance Management System (TAERS). This consisted of 2,181 M52A2 Tractors, 1,541 M54A2 Cargo trucks and 1,982 M51A2 Dump trucks. The cost and performance analyses were carried out separately for each of these trucks. Prior to use of the performance histories from the TAERS data bank, all vehicle histories were screened such that only data from vehicles with continuous histories were utilized in the study. The 5704 vehicles contained in the study had histories varying up to 65,000 miles of usage.

1.4 Conclusions.

Although the average system cost is indicated to reach a minimum beyond 60,000 miles (essentially the limit of the data) the average system cost was found to be very near its minimum at this mileage. Further, since none of the RAM parameters were determined to be degrading as the vehicle mileage was increasing, the economic life noted (60,000 miles) is considered the truck's useful life. By converting the mileage indications to years, the M39A2 5 Ton Truck is considered to have a 20 year life (based on 3,000 miles a year usage).

1.5 Recommendations.

It is recommended that (1) the life of the M39A2 Series 5 Ton Truck be extended from 13 years (as indicated in DA PEMA Policy and Guidance) to 20 years and (2) a mileage life for this truck be established at

60,000 miles (assuming replacement with a similar new vehicle).

2. INTRODUCTION

In a move by the Department of the Army to reassess the useful life of the tactical wheeled vehicle fleet, the Army Materiel Systems Analysis Activity (AMSAA) was tasked by the Army Materiel Command (Plans and Analysis Directorate) to conduct a Vehicle Average Useful Life Study which would have the following primary objectives:

1. Determine the age (mileage) at which it becomes economical to replace each of the four major payload tactical wheeled vehicles (1/4, 3/4 - 1 1/4, 2 1/2 and 5 ton vehicles).

2. Determine the economics of overhauling each of these wheeled vehicles and the remaining life after overhaul.

This report which is the second report pertaining to these objectives (see AMSAA TM No. 164 for the useful life determination of the M35A2 2 1/2 Ton Truck) will address the determination of the average useful life of the M39A2 series 5 ton truck.

3. DATA SOURCES

The data sources being utilized in this study consist of two separate Army data collection systems: (1) TAERS and (2) Sample Data Collection Program. The TAERS data collection system for vehicles was instituted by the Army in 1963 and was designed to collect detailed maintenance information on all vehicles in the U. S. Army fleet. This data collection system, however, was terminated in December 1969. The Sample Data Collection Program for vehicles was initiated in 1972 and was also designed to collect detailed maintenance data, however, only for a sample portion of the wheeled vehicle fleet. The Sample Data Collection Program also differs from TAERS in that the U. S. Army Tank-Automotive Command (TACOM) technical representatives which are in the field will monitor the data collection program in order to insure that there is more complete reporting of data than occurred under TAERS.

In utilizing these data sources, the TAERS data can only be utilized to investigate vehicle replacement life for new vehicles as no substantial quantity of data exists in TAERS for overhauled 5 ton vehicles (M39A2 Series). Data on overhauled 5 ton trucks are being collected in the Sample Data Collection Program and the economics of overhaul will be determined when sufficient data becomes available.

Of critical concern in the use of TAERS data for analysis purposes is the fact that many of the vehicle histories contained in the data bank are incomplete. This data omission problem is readily evident when vehicle histories are observed which show, for example, for a truck produced in late 1965 only one maintenance action reported in the time frame 1966 thru 1969. As regularly scheduled maintenance actions (at least semiannually) must have occurred with this vehicle during the 1966 to 1969 interval which should have been reported (scheduled as well as unscheduled maintenance actions are supposed to have been reported in the TAERS system) this truck obviously has incomplete data. Thus, in the use of TAERS data, it is important that periods of incomplete vehicle histories be eliminated from consideration.

The method used by AMSAA to distinguish complete from incomplete periods of vehicle histories involved the TAERS quarterly reporting system. Under TAERS, a quarterly report of any maintenance actions (scheduled or unscheduled) occurring within the quarter was required. Based on this requirement, the trucks that were selected for this study had to meet the criterion that there were at least four quarterly reports in a row (one year of continuous data) in the truck history. This criterion, although eliminating from consideration such vehicles as the one with one maintenance action in four years as well as vehicles with only intermittent reporting, did not entirely resolve the data omission problem. Although the vehicles selected by this criterion had at least one year of continuous data, it doesn't necessarily imply the vehicle's entire history was complete. For example, a vehicle produced in December 1965 may show TAERS reports in all four quarters in 1966 and the first three quarters of 1967 and subsequent to this period reports are indicated only for the third quarter of 1968 and the first and third quarter of 1969. Thus, after the third quarter of 1967 reporting became intermittent. The mileage noted on the vehicle during the first report in 1966 was, say 312 miles, with the mileage in the third quarter of 1967 being noted as 8,465 miles and the final mileage of 14,325 being noted by the report in the third quarter of 1969. If the missing quarters in 1968 and 1969 were ignored this vehicle history would be assumed to be complete through 14,325 miles. However, this may not be the case as maintenance actions may have occurred in the missing quarters of 1968 and 1969. Thus, for this study, only that part of the history that provided continuous reporting was used. In the above example, only the vehicle's history from 312 to 8,465 miles would be used. The screening of the TAERS vehicle histories according to the above method, it is pointed out, treats the data, it is felt, in a conservative manner. This is noted in the above example where the vehicle history was terminated at 8,465 miles, a mileage where a known maintenance action occurred rather than estimating how many additional maintenance free miles occurred after the last maintenance action and adding this mileage or some portion of the mileage to the 8,465 miles for the history termination mileage. It should also be pointed out that this vehicle history termination technique was not necessary for all vehicles as approximately 65% of the vehicles included in the study had continuous histories.

4. VEHICLE SAMPLE

The data used in this study were obtained from TAERS reporting on 5,704 M39A2 Series 5 Ton Trucks operated from 1965 thru 1969. The M39A2 trucks evaluated in the study consisted of the following three vehicles: (1) M52A2 Tractor, (2) M51A2 Dump Truck and (3) M54A2 Cargo Truck. A summary of the trucks contained in the study by body type, theatre of operation, and total mileage accumulated is shown below. It should be noted that the maximum mileage for an individual tractor or dump truck that was used in the study was 50,000 miles while the maximum mileage for an individual cargo truck was 65,000 miles.

TABLE 4.1 NUMBER OF VEHICLES INCLUDED IN STUDY

M39A2 5 TON TRUCK

BODY TYPE AND LOCATION	NO. VEHICLES	TOTAL MILES (MILLIONS)
M52A2 TRACTOR		
EUROPE	259	1.9
CONUS	907	2.8
OTHER	1015	12.6
TOTAL	2181	17.3
M51A2 DUMP		
EUROPE	153	1.1
CONUS	460	1.6
OTHER	1369	13.0
TOTAL	1982	15.7
M54A2 CARGO		
EUROPE	211	1.3
CONUS	602	1.5
OTHER	728	6.7
TOTAL	1541	9.5
GRAND TOTAL	5704	42.5

5. VEHICLE DESCRIPTION

The three 5 ton, 6x6, M39A2 series vehicles (M54A2 cargo truck, M52A2 tractor and M51A2 dump truck) are equipped with an LDS 465-1A engine which is a 6-cylinder, in-line, liquid-cooled, compression ignition engine designed to operate on a variety of fuels. The vehicles are designed for use over all types of roads, highways and cross-country terrain, and in all types of weather. They will ford hard bottom water crossings to a depth of 30 inches. All are equipped with a manually operated five speed transmission and two speed transfer case which transmits power to the front and rear axles. Service brakes are of the air-actuated, hydraulic type. All vehicles are equipped with a spare wheel and a tire, and a pintle hook at the rear permits towing of a trailer. The following specifically pertain to the three M39A2 series vehicles included in the study:

a. M54A2 Cargo Truck. The 5 Ton, 6x6, M54A2 Cargo Truck has a 179-inch wheelbase with 11:00 x 20 tires and dual rear wheels. A 14-foot flat bed cargo body is mounted on the rear.

b. M52A2 Tractor. The 5 Ton, 6x6, M52A2 tractor has a 167-inch wheelbase with 11:00 x 20 tires and dual rear wheels. A fifth wheel assembly, approach plates, and deck plate, suitable for hauling trailers, are mounted on the rear of the chassis. Tractor-to-trailer brake hoses and connections are mounted behind the cab.

c. M51A2 Dump Truck. The 5 Ton, 6x6, M51A2 Dump Truck has a 167-inch wheelbase with 11:00 x 20 tires and dual rear wheels. A 5-cubic yard capacity dump body and twin-cylinder hoist assembly is mounted on the rear of the chassis.

6. USEFUL LIFE ASSESSMENT METHODOLOGY

The economic life of the M39A2 Series 5 Ton Trucks (M54A2 Cargo, M52A2 Tractor and M51A2 Dump Truck) has been assessed by determining the mileage at which the average system cost per mile (costs associated with the acquisition, shipping and maintenance of the truck) is minimized (truck economic life). In addition, an evaluation of the vehicle's Reliability, Availability and Maintainability (RAM) performance characteristics over the economic life span has been made to establish if the vehicle's useful life should be considered less than the vehicle's economic life. This may occur, for example, if a truck at some mileage prior to the economic life mileage began having frequent breakdowns due to a relatively inexpensive component failure. This type of breakdown may not have much effect on the cost analysis but may result in a substantial reduction in the vehicle's reliability prior to the economic life mileage. If, however, the RAM parameters do not appreciably degrade throughout the economic life of the truck, then the useful life would be equal to the economic life of the truck.

7. TAERS DATA ANALYSIS

In exercising the above methodology, the procedure employed was to analyze the maintenance costs (scheduled and unscheduled) to determine how the costs were changing as the vehicle increased in mileage. This procedure was also carried out for the analysis of the RAM characteristics.

The TAERS data provided information on the maintenance actions (both scheduled and unscheduled) required for the vehicles as the vehicles increased in mileage. In particular, for each maintenance action, the following data were recorded: date action occurred, mileage at which action occurred, maintenance level (organization or support), man-hours required, failure detection code (i.e., whether the action was detected in normal operation of the vehicle, during an inspection or is just a regularly scheduled maintenance action), remedial action taken (repaired, replaced, adjusted or is simply the result of normal services), part name and Federal Stock Number, and quantity of parts replaced.

The analysis of the data from a cost standpoint utilized the parts cost contained in the Army Master Data File. The cost information is in 1974 dollars and was supplied to AMSAA by TACOM. The mean labor rate used in this study was $6.02 an hour. It is noted that there were approximately 190,000 maintenance actions for the 5,704 vehicle sample and about half of these were parts replacements. As noted earlier in this report, data omission presented a serious problem in the analysis of TAERS data. As a result of this problem many vehicle histories were incomplete. For example, the vehicle discussed earlier was considered to have a complete history only from 312 to 8465 miles. Other vehicles had histories beginning and ending at various different mileages. In the costing of the maintenance actions by mileage, it was thus necessary to be aware of each vehicle's mileage interval. The costing procedure involved determining the total cost (parts and labor) experienced by the vehicles for each 100 mile interval. In this compilation, the vehicle with a history of 312 to 8465 miles only contributed to the cost total beginning with the 300 to 400 mile interval and ending with the 8400 to 8500 mile interval. Thus, the sample size for each 100 mile interval varied. This procedure, as mentioned earlier, probably conservatively estimates the costs sustained as the vehicle which is noted to have its last maintenance action at 8,465 miles probably traveled some additional miles without having to sustain any additional maintenance actions but in the procedure employed the vehicle was considered to contribute to the cost input upto 8500 miles only.

The analysis of the TAERS data from a RAM standpoint presented an additional problem. Normally in the analysis of data for the determination of reliability and availability estimates, failure data is required. However, from the TAERS data it is extremely difficult, if not impossible, to determine for all unscheduled maintenance actions which actions are reliability failures. As a result of this fact, an analysis of all unscheduled maintenance actions was undertaken rather than the usual analysis of failures. Specifically, the analysis consisted of three phases, all with the objective of determining how the vehicle's performance was changing as the vehicle increased in mileage: (1) Unscheduled Maintenance Action Analysis - The goal of this analysis was to determine the probability of completing 75 miles without an unscheduled maintenance action (UMA) for continually increasing mileages, (2) Inherent Readiness Analysis - The goal of this analysis was to determine as a function of mileage, the probability that the vehicle is not undergoing active repair due to an unscheduled maintenance action when required for use at a random point in time, and (3) Maintainability Analysis - This analysis consisted of determining, as a function of mileage, the maintenance support index (MSI), the average man-hours required per vehicle per 1000 miles of usage, and the average man-hours required per maintenance action.

8. DATA PROCESSING

The large volume of data involved in this study (over 1,150,000 lines of data) required substantial electronic data processing. All data processing was conducted at Aberdeen Proving Ground using the Ballistic Research Laboratories Electronic Scientific computers (BRLESC I and II) and the UNIVAC 1108 computer. The programs utilized in the study (see Figure 8.1 and Table 8.1) were written in FORTRAN, FORAST, OMNITAB II, and BRLESC Assembly Language. The flowchart shown on Figure 8.1 represents the major programs, the input and output relations, the large print-outs generated, and the manual operations directly related to the automated processing in the study. It should be mentioned here that it is not the intention of the authors to present the computer programs in detail, this will be done in a later report, but rather to provide the reader with an overall view of the computer programming effort required for this study.

The TAERS data utilized in this study were received from the U. S. Army Maintenance Management Center (USAMMC) on magnetic computer tape in IBM bit code. The 17 data tapes received had to be translated to BRLESC bit code and reformatted to TAERS format after translation. Each of the tapes was then decoded into a more readable, columniated, and labelled form written on output tapes from which a paper copy was printed. These decoded tapes were then screened for errors; concurrently, listings of replacement parts were extracted from the TAERS format tapes.

From each tape, a list of replacement parts with distinct FSN's was accumulated, sorted, and placed in a separate tape file. These files were then merged. The resulting parts file was then printed with a special format, and forwarded to the U. S. Army Tank-Automotive Command (TACOM) for editing and costing. The parts file was also sorted by FIIN (last 7 digits of FSN), printed in that order, and likewise forwarded to TACOM. In a similar fashion, a list of entries without reported man-hours was compiled and forwarded to TACOM.

The screening and correction of the basic data involved seven programs. The lines of each vehicle history were placed in order of date and the mileage sequences were checked. A history with a single mileage discrepancy was corrected by replacing the mileage entry in question by the mean of the prior and subsequent mileage entries. Two or more mileage discrepancies caused the vehicle under examination to be deleted from further consideration in the study. The data were subsequently screened for large gaps between reporting dates (missing quarters) and only that portion of each history free of intermittent reporting was accepted for use. Following the computerized error detection and correction, the data were manually examined for those infrequently occurring errors which are not readily detected by computer. A list of vehicles with such errors was prepared, and these histories were removed from the data tapes.

The processing of the data included the determination of the following: the usage rate of each vehicle; the mileage interval covered by each vehicle; the average number of, and man-hours expended for each maintenance action; the rate of unscheduled maintenance actions; the total frequency of each part replaced; the identification of vehicles requiring replacement of major components, and the cost of maintenance by 100 mile intervals. Additionally, a weighted polynomial regression curve fitting procedure was applied to the cost data, and the minimum value of average system cost function was determined.

The electronic data processing described above included 37 major programs, and approximately 15 minor programs, most of which were executed for each of the 17 reels of TAERS data analyzed. The automated portion of this study required the full commitment of 175 reels of magnetic tape, the use of over 50,000 computer punch cards, and the generation of over 20 linear feet of computer print-out.

FIGURE 8.1 COMPUTER SYSTEM FLOWCHART

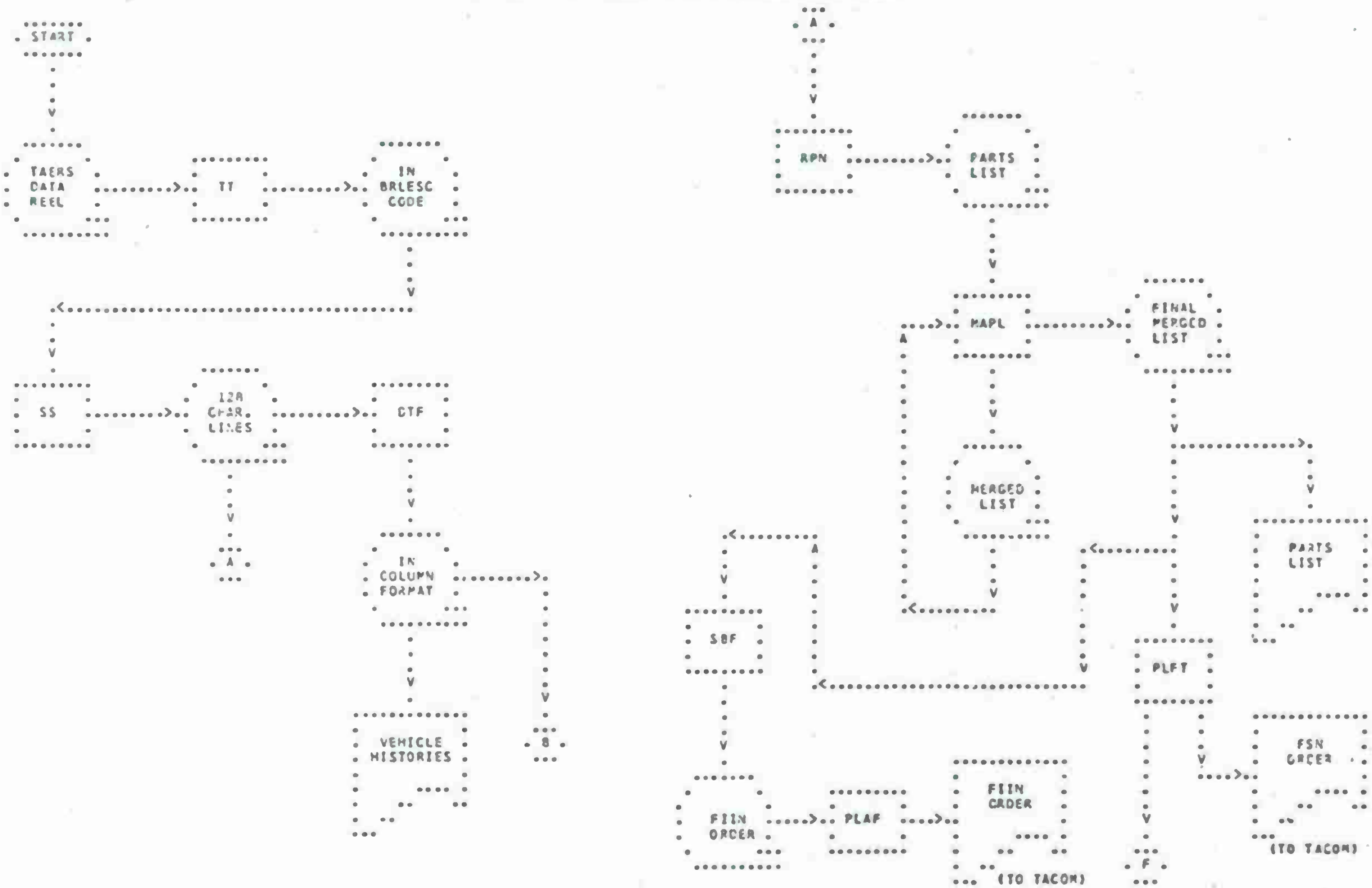


FIGURE 8.1 (Cont'd)

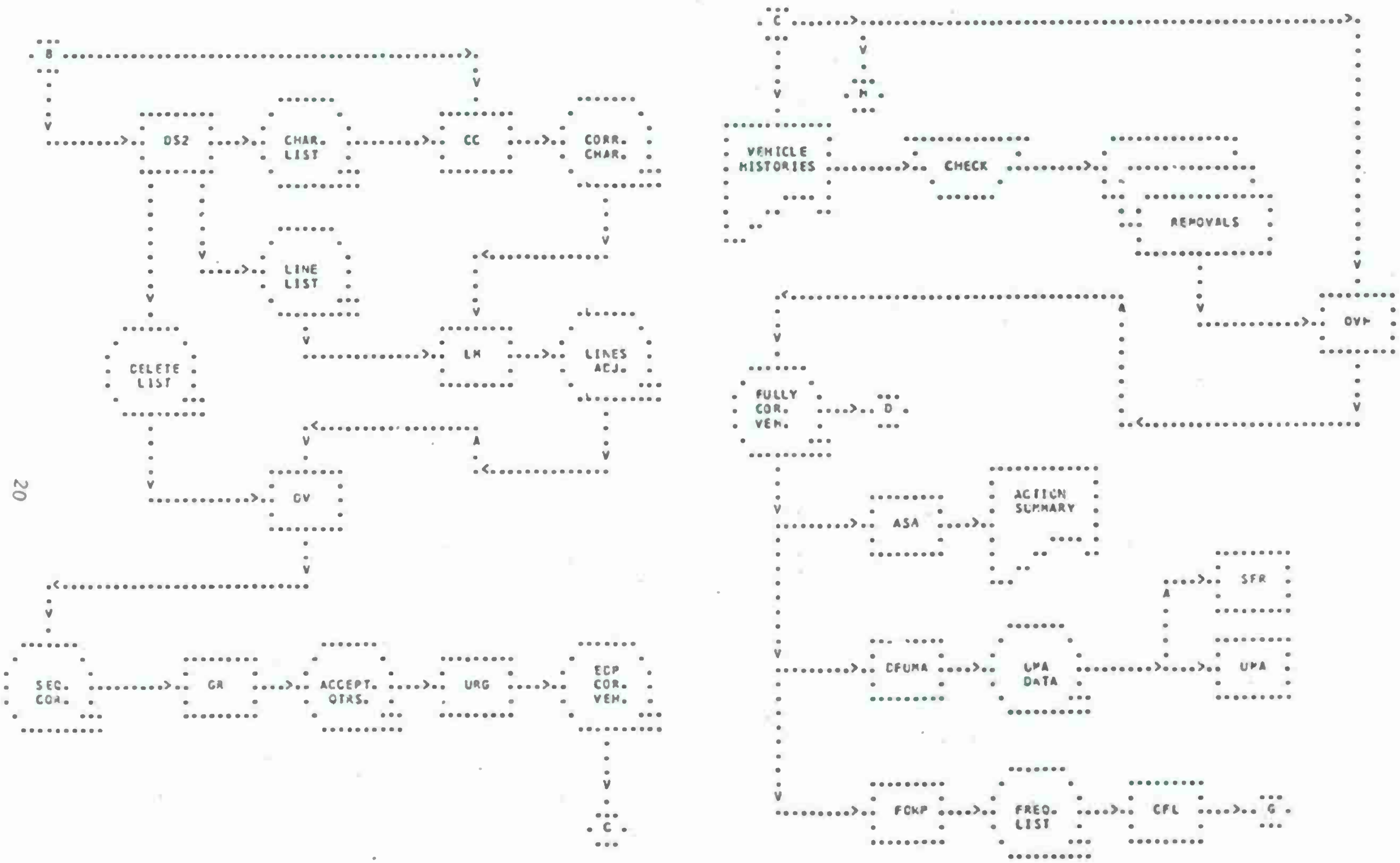


FIGURE 8.1 (Con'd)

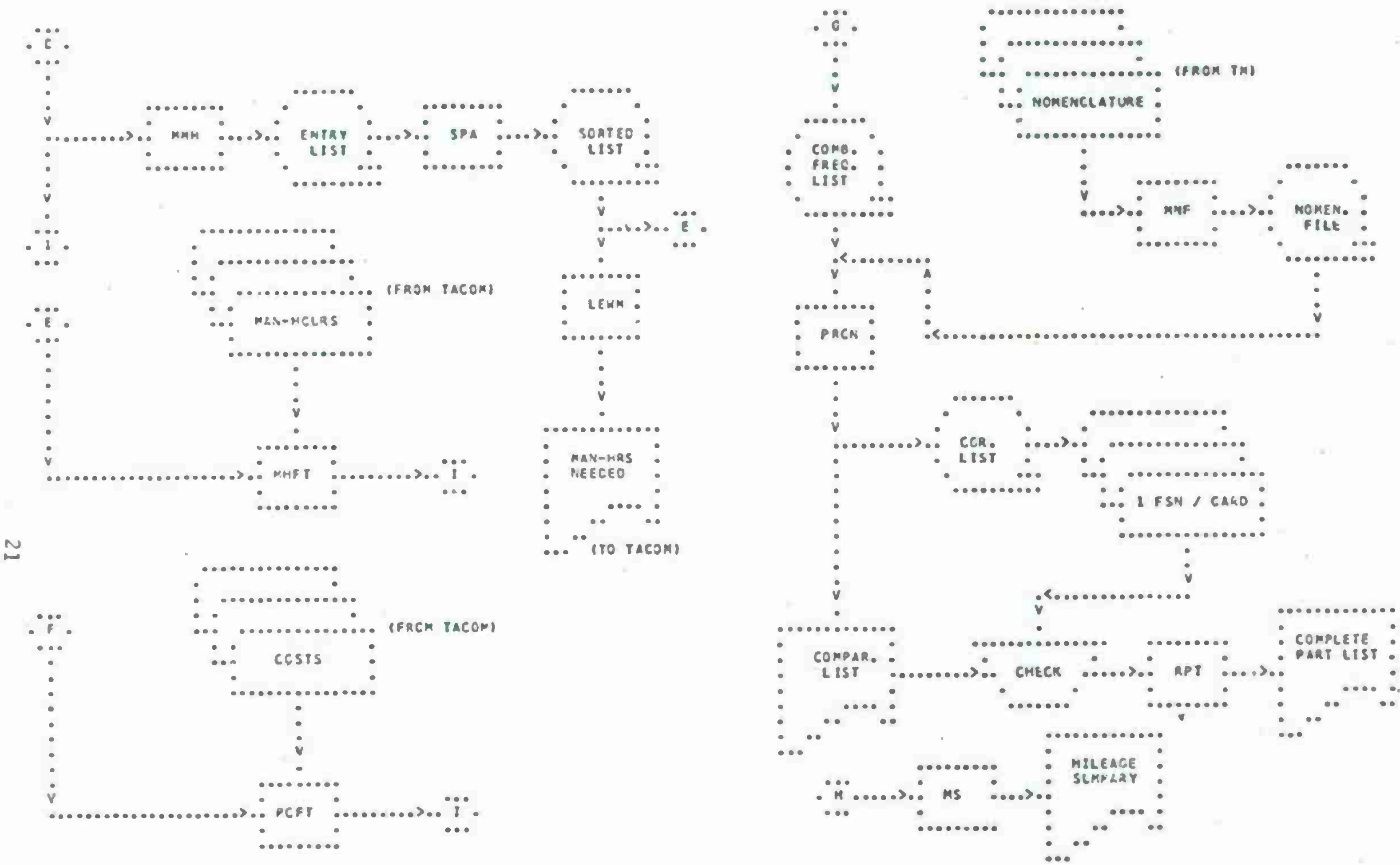


FIGURE 8.1 (Cont'd)

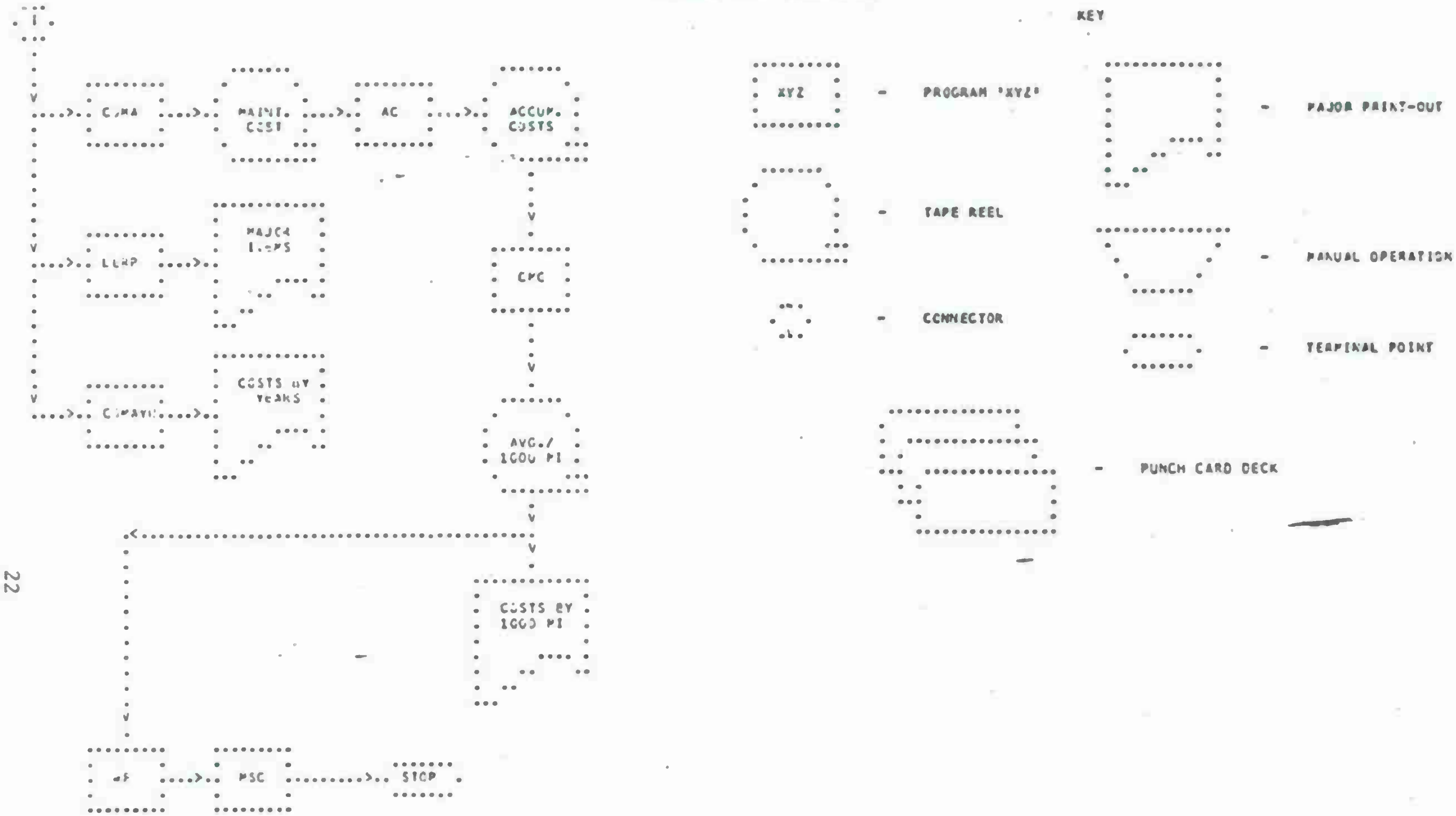


TABLE 8.1 DESCRIPTION OF COMPUTER PROGRAMS

CODE LETTERS	PURPOSE
TT	Translation of bit code on magnetic computer tapes containing TAERS data.
SS	Realignment of translation output into TAERS format.
DTF	Decoding of TAERS format into readable columniated form.
RPN	Extraction from each reel of TAERS data, of names and FSN's of all parts replaced.
MAPL	Merging of lists of replacement parts from multiple data files, into a single list ordered by FSN.
PLFT	Printing of parts' list with a special format suitable for entry of cost data by TACOM.
SBF	Sorting of parts' list into FIIN order.
PLAF	Printing of parts' list in FIIN order using special format.
DS2	Screening of data to order each vehicle history by date, and check mileage sequence. This program generates instructions to correct characters, move lines, and delete entire vehicle histories, as required.
CC	Physical correction on magnetic tape, of mileages found in error by DS2. (Correction limited to one mileage change per vehicle.)
LM	Movement of lines into proper date order as determined by DS2.
DV	Deletion of vehicle histories found to be unusable due to mileage discrepancies. (Two or more mileages in error in same vehicle history.)

TABLE 8.1 (Cont'd)

CODE LETTERS	PURPOSE
GR	Determination and isolation of usable quarters of each data history.
URG	Calculation of annual usage rate for each vehicle based on usable data.
OVH	Removal from data tapes of vehicle histories found to be in error by manual check.
ASA	Determination of average number of maintenance actions per year, average man-hours per action, etc.
DFUMA	Extraction from history tapes of data concerning unscheduled maintenance actions.
SFR	Calculation of observed rate of unscheduled maintenance action per 1000 mile interval.
UMA	Weibull maximum likelihood estimation of overall rate of unscheduled maintenance actions.
FORP	Calculation of frequency of occurrence of each replacement FSN, for each reel of corrected histories.
CFL	Merging of frequency lists obtained by FORP.
MMH	Extraction from each reel of histories, of actions which do not have man-hours reported.
SPA	Sorting of descriptions of actions found by MMH, to form an organized list.
LEWM	Printing of entries lacking man-hours, using a special format suitable for entry of man-hours by TACOM.

TABLE 8.1 (Cont'd)

CODE LETTERS	PURPOSE
MHFT	Establishment of man-hour reference file based on data from TACOM.
PCFT	Establishment of parts' cost reference file based on data from TACOM.
MNF	Establishment of parts' nomenclature reference file based on data in Technical Manuals.
PRCN	Printing of a comparison list showing reported and corrected nomenclature, and insertion of correct nomenclature into part frequency list file tape.
RPT	Sorting and printing of replacement parts' list in FSN order, frequency order, and cost order.
MS	Summarization of each vehicle listing serial number, beginning and ending mileages and dates, etc.
LERP	Location of vehicle histories which indicate replacement of major components.
COMA	Determination by 100 mile interval, of number of vehicles, maintenance actions, and man-hours; of cost of labor and parts; etc.
AC	Accumulation of output of COMA from each reel of vehicle histories.
CMC	Combination of cost data into 1000 mile intervals.
COMAYU	Determination of parts' and labor cost by year of usage.
WF	Weighted polynomial regression curve fitting to cost data.
MSC	Minimization of average system cost function.

TABLE 8.1 (Cont'd)

NOTE: These thirty-seven programs comprise the major computer programs used for the Vehicle Average Useful Life Study of the 5 Ton Vehicle. In addition, approximately 15 minor programs were used for tape operations; file searches; plotting; repetitive calculations such as determining percentages for various tables; record mode interface; etc.

9. COST ANALYSIS

As noted earlier, the object of the cost analysis was to determine how the maintenance costs were varying as the truck mileage was increasing in order that the average system cost could be minimized. Thus, all the maintenance actions occurring with these trucks (2181 tractor, 1541 cargo, and 1982 dump) were costed in constant FY 74 dollars (parts and labor) as a function of mileage. See Tables 9.1, 9.2, and 9.3 for a summary of the costs as a function of mileage (in 1000 mile intervals) for mileages from 0 to 50,000 for the tractor and dump truck and from 0 to 65,000 for the cargo truck.

The methodology employed in the analysis of this data involved the determination of a continuous instantaneous maintenance cost curve (the instantaneous maintenance cost refers to the maintenance cost per mile at a specific mileage). This curve was used to obtain the cumulative maintenance cost curve and an average system cost curve (the system cost refers to all those costs associated with the procurement, shipment, and maintenance of a vehicle including such costs as the vehicle's acquisition price, administrative expenses sustained, tooling costs, first and second destination charges, and maintenance costs). From the average system cost curve, the mileage at which the average system cost is at a minimum can be determined which represents the point where the overall average cost to the Army to procure, ship, and maintain the vehicle fleet is at a minimum.

In determining the continuous instantaneous maintenance cost curve, it was necessary to conduct two separate cost analyses. This was due to the high frequency of engine replacements and their high cost ($3300 each) relative to the other maintenance action costs. Consequently, a continuous instantaneous maintenance cost curve was determined for all maintenance actions excluding engine replacements and a similar cost curve for engine replacement actions only was also determined. From these two curves, a continuous instantaneous overall maintenance cost curve was generated.

In the analysis of the average maintenance cost data excluding engine replacement costs, weighted regression analysis techniques were applied. A second degree polynomial with a logarithmic transformation of the independent variable (mileage) was found to represent the data beginning at 1000 miles. The average maintenance cost data for the 0-1000 mile interval was thus considered as the constant in determining the cumulative maintenance cost curve. Since no significant difference was found between the three cost curves representing the different body types, the data were combined and a combined cost curve was determined. Again, a second degree polynomial with a logarithmic transformation of the independent variable (mileage) was found to best fit the data (See Figure 9.1). Tests of significance indicated the coefficients were highly significant (.01 level). The function determined was:

TABLE 9.1

COST DATA FOR THE M52A2 5 TON TRACTOR

MILEAGE INTERVAL (1000's)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. & UNSCH.)	NO. OF MAN-HRS	TOTAL LABOR COST (DOLLARS)	PARTS COST (DOLLARS)			TOTAL COST (DOLLARS)
					ALL PARTS EXCEPT ENGINE	ENGINE	TOTAL	
0- 1	1034	17455	38976	234635	113649	59400	173049	407684
1- 2	1212	8625	23192	139617	84717	69300	154017	293634
2- 3	1103	4762	15159	91259	68493	49500	117993	209252
3- 4	1016	4292	12473	75087	60414	75900	136314	211402
4- 5	948	3378	10280	61887	60021	75900	135921	197808
5- 6	875	2339	6250	37626	43264	66000	109264	146890
6- 7	815	2768	8274	49810	50455	122100	172555	222365
7- 8	776	2350	6324	38069	50347	118800	169147	207216
8- 9	738	2275	6595	39703	46655	112200	158855	198558
9-10	692	2396	7413	44626	44773	102300	147073	191699
10-11	667	2110	5706	34347	40119	99000	139119	173467
11-12	628	1759	4838	29122	35211	99000	134211	163332
12-13	592	2068	5775	34768	42631	102300	144931	179699
13-14	547	1749	5068	30509	31975	82500	114475	144984
14-15	519	1575	4165	25076	33239	112200	145439	170515
15-16	482	1584	4488	27015	26300	141900	168200	195215
16-17	447	1510	4637	27912	29400	92400	121800	149712
17-18	422	1333	3709	22330	23238	102300	125538	147868
18-19	387	1262	3514	21154	22088	85800	107888	129043
19-20	363	1184	3415	20557	21765	66000	87765	108322
20-21	330	1149	2771	16681	19107	82500	101607	118288
21-22	296	909	2395	14415	13946	56100	70046	84461
22-23	262	684	1856	11175	13028	33000	46028	57203
23-24	234	792	1849	11128	22466	59400	81866	92994
24-25	222	678	1987	11959	12298	49500	61798	73757
25-26	210	713	1905	11470	12257	46200	58457	69927
26-27	195	574	1469	8841	13075	33000	46075	54916
27-28	166	418	1162	6997	9386	23100	32486	39482
28-29	147	445	1055	6350	13968	19800	33768	40119
29-30	133	483	1044	6286	8146	26400	34546	40832
30-31	122	514	1410	8491	8056	42900	50956	59447
31-32	102	381	1012	6090	7143	33000	40143	46232
32-33	92	332	649	3905	5712	33000	38712	42617
33-34	83	265	631	3801	8053	23100	31153	34954
34-35	75	202	459	2761	4977	16500	21477	24238
35-36	70	239	597	3596	3556	16500	20056	23652
36-37	64	217	501	3014	5124	9900	15024	18038
37-38	56	236	554	3337	5434	23100	28534	31871
38-39	45	101	179	1079	2248	3300	5548	6627
39-40	40	74	188	1132	1505	0	1505	2637
40-41	35	68	177	1068	1067	3300	4367	5435
41-42	30	93	193	1161	2144	6600	8744	9906
42-43	26	93	246	1482	1920	3300	5220	6703
43-44	21	63	195	1174	2460	3300	5760	6934
44-45	18	47	103	618	1732	0	1732	2350
45-46	15	71	86	516	914	0	914	1430
46-47	13	48	179	1075	746	3300	4046	5120
47-48	13	42	87	524	1279	3300	4579	5104
48-49	13	30	79	475	203	3300	3503	3978
49-50	9	24	39	235	291	0	291	526

TABLE 9.2

COST DATA FOR THE M51A2 5 TON DUMP TRUCK

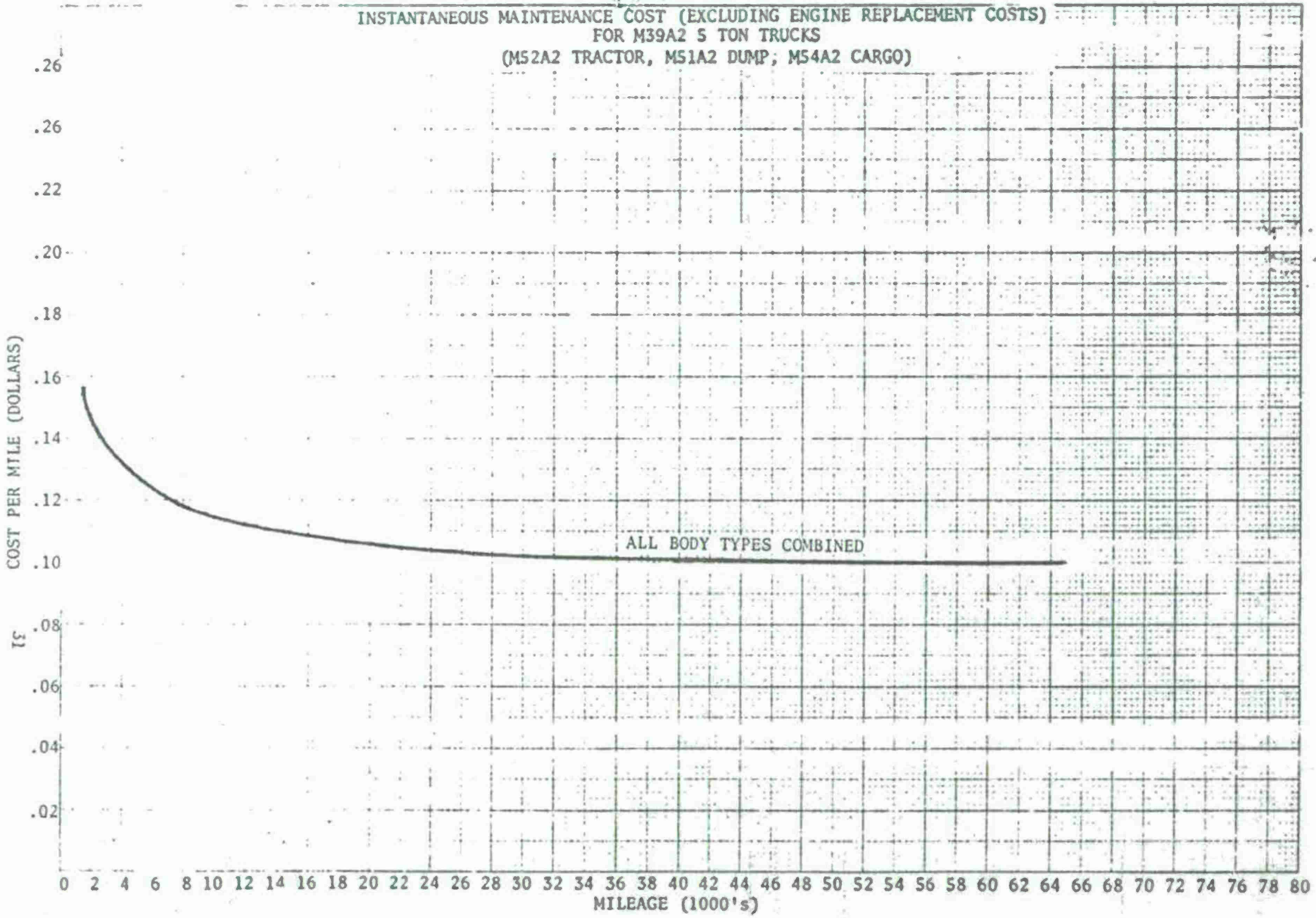
MILEAGE INTERVAL (1000's)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. & UNSCH.)	NO. OF MAN-HRS	TOTAL LABOR COST (DOLLARS)	PARTS COST (DOLLARS)			TOTAL COST (DOLLARS)
					ALL PARTS EXCEPT ENGINE	ENGINE	TOTAL	
0- 1	975	10508	26111	157189	72752	29700	102452	259641
1- 2	1194	5868	13547	81551	68513	36300	104813	186364
2- 3	1070	4982	11800	71037	69925	33000	102925	173963
3- 4	945	4490	10233	61601	65841	19800	85641	147242
4- 5	873	3475	8490	51110	60351	82500	142851	193961
5- 6	842	3143	6997	42124	49639	49500	99139	141263
6- 7	807	3098	8107	48806	51545	62700	114245	163051
7- 8	771	2495	6221	37450	53830	59400	113230	150680
8- 9	734	2760	7621	45878	52253	69300	122553	168431
9-10	683	2319	5688	34245	42624	62700	105324	139568
10-11	631	2188	5677	34175	44767	59400	104167	138342
11-12	597	2027	4824	29041	40463	99000	139463	168504
12-13	553	1947	5576	33569	42350	69300	111650	145219
13-14	498	1654	3604	21693	34941	62700	97641	119334
14-15	453	1456	3179	19137	29142	62700	91842	110979
15-16	413	1336	3118	18771	30802	46200	77002	95773
16-17	373	1248	2912	17528	25308	33000	58308	75836
17-18	345	1044	2144	12904	20730	42900	63630	76534
18-19	305	1099	2640	15891	16652	46200	62852	78744
19-20	275	721	1677	10093	12948	33000	45948	56041
20-21	257	809	1943	11700	14260	33000	47260	58960
21-22	235	704	1346	8104	12733	33000	45733	53837
22-23	217	624	1389	8362	13046	23100	36146	44508
23-24	197	624	1149	6918	11583	19800	31383	38302
24-25	179	426	948	5706	6686	16500	23186	28892
25-26	161	462	1099	6618	7125	39600	46725	53343
26-27	144	468	1237	7449	5788	23100	28888	36337
27-28	127	438	1171	7051	6607	29700	36307	43358
28-29	113	373	806	4852	11069	16500	27569	32421
29-30	103	257	502	3025	5603	16500	22103	25127
30-31	94	265	604	3636	4662	9900	14562	18198
31-32	83	274	757	4559	5082	9000	14982	19541
32-33	74	165	492	2960	2068	9900	11968	14928
33-34	65	168	501	3015	2710	9900	12610	15625
34-35	56	149	355	2134	2639	6600	9239	11374
35-36	53	159	371	2236	3979	9900	13879	16114
36-37	46	90	199	1199	2070	9900	11970	13169
37-38	43	106	268	1616	2159	0	2159	3774
38-39	38	115	339	2042	2282	9900	12182	14224
39-40	34	110	261	1572	1477	6600	8077	9649
40-41	29	61	142	858	1497	6600	8097	8955
41-42	24	63	134	809	970	0	970	1779
42-43	23	38	128	768	755	6600	7355	8123
43-44	20	50	220	1327	790	0	790	2117
44-45	16	23	55	328	414	3300	3714	4043
45-46	15	14	64	388	44	3300	3344	3732
46-47	14	28	28	167	230	0	230	398
47-48	13	21	59	355	240	3300	3540	3896
48-49	10	26	51	309	359	3300	3659	3967
49-50	9	32	81	488	610	3300	3910	4397

TABLE 9.3

COST DATA FOR THE M54A2 5 TON CARGO TRUCK

MILEAGE INTERVAL (1000's)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. & UNSCH.)	NO. OF MAN-HRS	TOTAL LABOR COST (DOLLARS)	PARTS COST (DOLLARS)			TOTAL COST (DOLLARS)
					ALL PARTS EXCEPT ENGINE	ENGINE	TOTAL	
0- 1	643	9081	21637	130256	50737	26400	77137	207393
1- 2	821	5558	13839	83311	55892	26400	82292	165603
2- 3	768	4026	10346	62284	45270	26400	71670	133954
3- 4	687	3588	8904	53602	45551	36300	81851	135453
4- 5	600	2702	6769	40748	38747	49500	88247	128995
5- 6	520	2354	6219	37439	40228	52800	93028	130467
6- 7	440	1899	4759	28652	30795	19800	50595	79247
7- 8	391	1346	3002	18072	24771	23100	47871	65943
8- 9	347	1315	3102	18672	21136	33000	54136	72809
9-10	315	1126	2590	15592	21650	33000	54650	70242
10-11	289	1047	2581	15539	19305	49500	68805	84343
11-12	261	902	1975	11889	14358	16500	30858	42747
12-13	232	733	2135	12852	11898	42900	54798	67650
13-14	209	566	1211	7290	9840	23100	32940	40230
14-15	187	586	1316	7921	7304	23100	30404	38325
15-16	175	508	1335	8034	6894	36300	43194	51228
16-17	163	421	1029	6195	8387	13200	21587	27782
17-18	147	388	802	4829	7606	6600	14206	19036
18-19	131	471	1219	7340	6240	13200	19441	26781
19-20	117	326	820	4936	5030	16500	21530	26466
20-21	108	239	657	3953	2495	9900	12395	16348
21-22	99	365	1010	6081	6053	13200	19253	25335
22-23	90	294	838	5048	3011	16500	19511	24558
23-24	82	305	963	5797	2947	26400	29347	35144
24-25	73	254	579	3486	4004	9900	13904	17389
25-26	69	218	558	3357	2955	9900	12855	16212
26-27	65	193	553	3332	2080	13200	15280	18612
27-28	63	221	643	3871	2610	19800	22410	26280
28-29	60	143	397	2389	1846	3300	5146	7535
29-30	53	149	337	2029	1536	6600	8136	10165
30-31	53	158	510	3070	1718	13200	14918	17998
31-32	55	155	374	2248	1621	3300	4921	7169
32-33	52	213	568	3421	2356	9900	12256	15678
33-34	50	150	331	1992	1301	3300	4601	6595
34-35	47	135	229	1377	1797	3300	5097	6474
35-36	47	191	515	3098	3838	6600	10438	13536
36-37	45	136	277	1670	1749	0	1749	3418
37-38	45	169	437	2632	2451	6600	9051	11682
38-39	45	199	493	2970	2965	6600	9565	12536
39-40	43	218	589	3548	3032	13200	16232	19779
40-41	43	196	455	2742	1936	0	1936	4678
41-42	46	232	552	3321	3181	13200	16381	19702
42-43	47	181	430	2586	1411	3300	4711	7296
43-44	45	247	601	3616	2661	16500	19161	22777
44-45	44	139	459	2764	1427	13200	14627	17390
45-46	45	165	368	2214	1574	3300	4874	7087
46-47	44	164	391	2353	2464	3300	5764	8117
47-48	45	193	536	3226	3692	9900	13592	16817
48-49	43	171	529	3183	185	13200	15059	18242
49-50	41	146	404	2431	2337	0	2337	4769
50-51	40	129	322	1938	1955	6600	8555	10493
51-52	38	122	267	1609	1042	0	1042	2651
52-53	36	140	379	2282	1577	0	1577	3859
53-54	34	63	187	1125	349	6600	6949	8074
54-55	33	103	293	1761	1693	0	1693	3454
55-56	31	124	369	2219	940	9900	10840	13059
56-57	31	58	133	802	294	0	294	1097
57-58	31	97	344	2068	1560	13200	14760	16827
58-59	28	89	212	1277	616	3300	3916	5193
59-60	24	62	257	1550	871	0	871	2421
60-61	24	46	118	712	162	0	162	874
61-62	22	73	225	1353	536	6600	7136	8490
62-63	17	42	104	628	255	0	255	883
63-64	14	16	55	331	251	0	251	582
64-65	9	28	120	719	153	0	153	872

FIGURE 9.1
INSTANTANEOUS MAINTENANCE COST (EXCLUDING ENGINE REPLACEMENT COSTS)
FOR M39A2 5 TON TRUCKS
(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)



$$f_1(x) = .17 - .032\ln x + .0037 \ln^2 x$$

where

$f_1(x)$ = instantaneous maintenance cost (dollars per mile) excluding engine replacement costs

x = truck mileage (1000's of miles) ≥ 1

In the analysis of the engine replacement actions, a Mann Trend test was initially carried out on those vehicles with maintenance histories starting at essentially zero mileage and having more than one engine replacement throughout its history. The purpose of this test was to determine whether or not the mean mileage between engine replacements (mileage to first replacement, mileage between first and second replacement, mileage between second and third replacement, etc.) was constant. The results of this test were highly significant (.01 level) and indicated the mean mileage between engine replacements to be decreasing (see section 10 for an additional discussion of engine replacement intervals). Based on these results, a Weibull intensity function was fitted to the engine replacement data (mileages) and was found to represent the data. However, it was found that the three different body types could not be represented by a single function as in the analysis of the average maintenance cost data excluding engine replacement costs. From the Weibull intensity function, the following continuous instantaneous cost curves for engine replacement actions (See Figure 9.2) were determined:

$$f_2(x) = .055x^{.4321} \quad \text{(tractor)}$$

$$f_2(x) = .041x^{.3687} \quad \text{(cargo)}$$

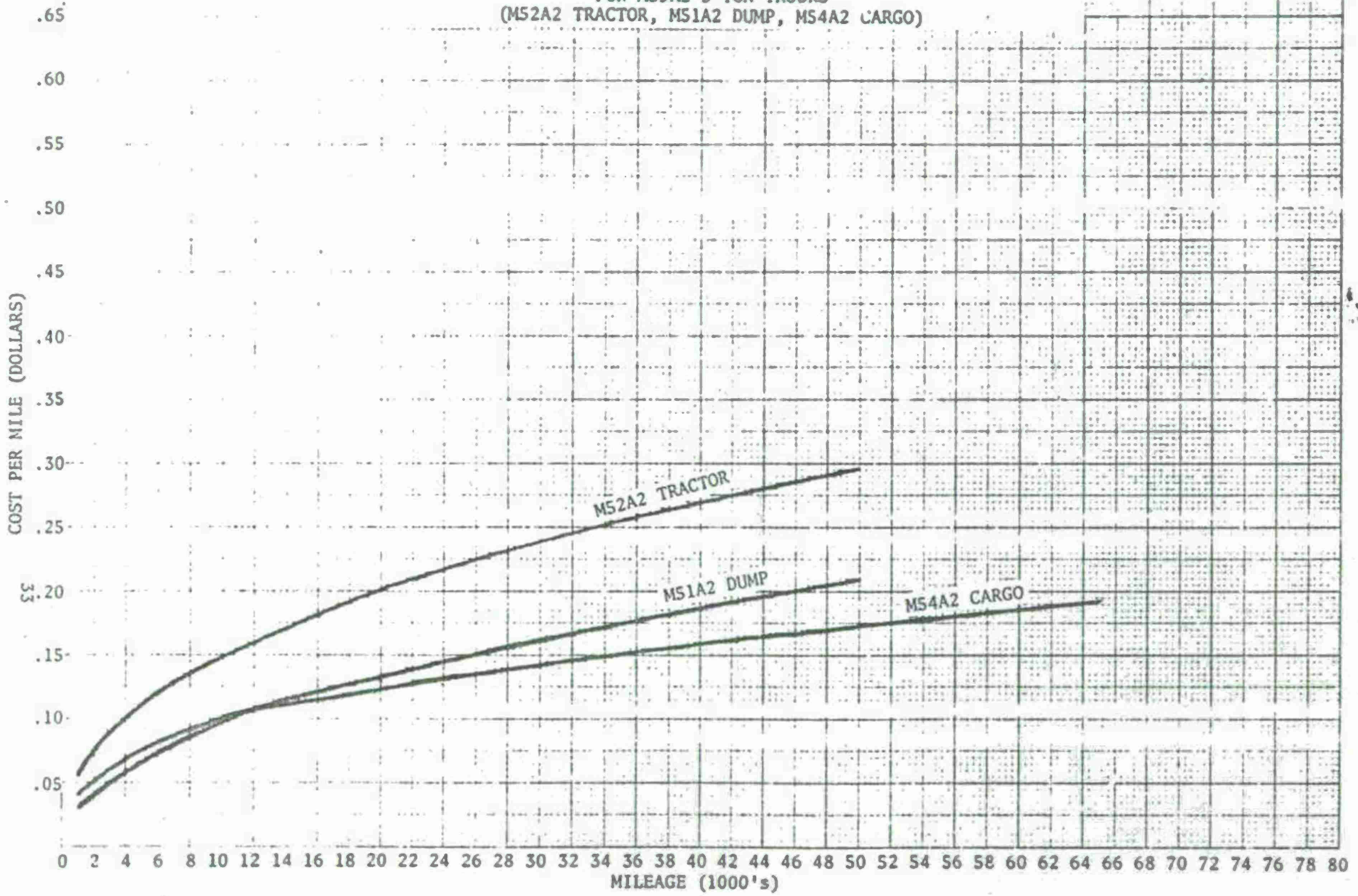
$$f_2(x) = .031x^{.4887} \quad \text{(dump)}$$

where

$f_2(x)$ = instantaneous engine replacement cost (dollars per mile)

x = truck mileage (1000's of miles)

FIGURE 9.2
INSTANTANEOUS MAINTENANCE COST (ENGINE REPLACEMENT COSTS ONLY)
FOR M39A2 5 TON TRUCKS
(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)



Utilizing the above functions $f_1(x)$ and $f_2(x)$, the following instantaneous overall maintenance cost curves (See Figure 9.3) were determined:

$$f(x) = .17-.032\ln x+.0037\ln^2 x+.055x^{.4321} \quad \text{(tractor)}$$

$$f(x) = .17-.032\ln x+.0037\ln^2 x+.041x^{.3687} \quad \text{(cargo)}$$

$$f(x) = .17-.032\ln x+.0037\ln^2 x+.031x^{.4887} \quad \text{(dump)}$$

where

$f(x)$ = instantaneous overall maintenance cost (dollars per mile)

x = truck mileage (1000's of miles) ≥ 1

From the continuous instantaneous overall maintenance cost curve, the cumulative maintenance cost curve was obtained. However, as previously noted, the average maintenance cost excluding engine replacement costs for the 0-1000 mile interval was considered as a constant in determining this function. The functions determined (See Figure 9.4) were:

$$F(x) = 129.14+207.69x+38.155x^{1.4321}-39.25x\ln x +3.70x\ln^2 x \quad \text{(tractor)}$$

$$F(x) = 28.15+207.69x+29.940x^{1.3687}-39.25x\ln x +3.70x\ln^2 x \quad \text{(cargo)}$$

$$F(x) = 73.79+207.69x+20.685x^{1.4887}-39.25x\ln x +3.70x\ln^2 x \quad \text{(dump)}$$

where

$F(x)$ = cumulative maintenance cost (FY 74 dollars)
x = truck mileage (1000's of miles) ≥ 1

FIGURE 9.3

INSTANTANEOUS OVERALL MAINTENANCE COST FOR M39A2 5 TON TRUCKS
(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)

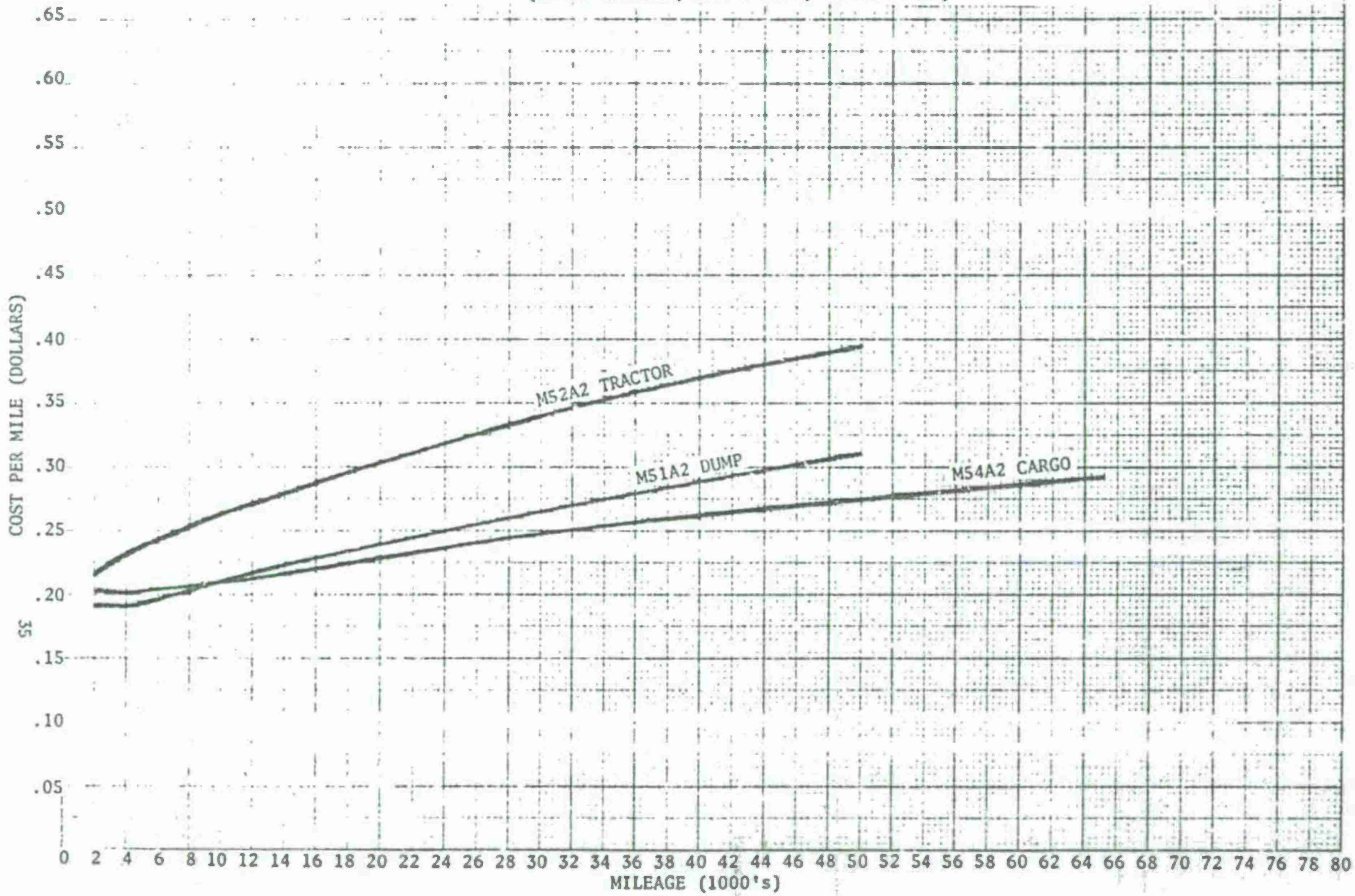
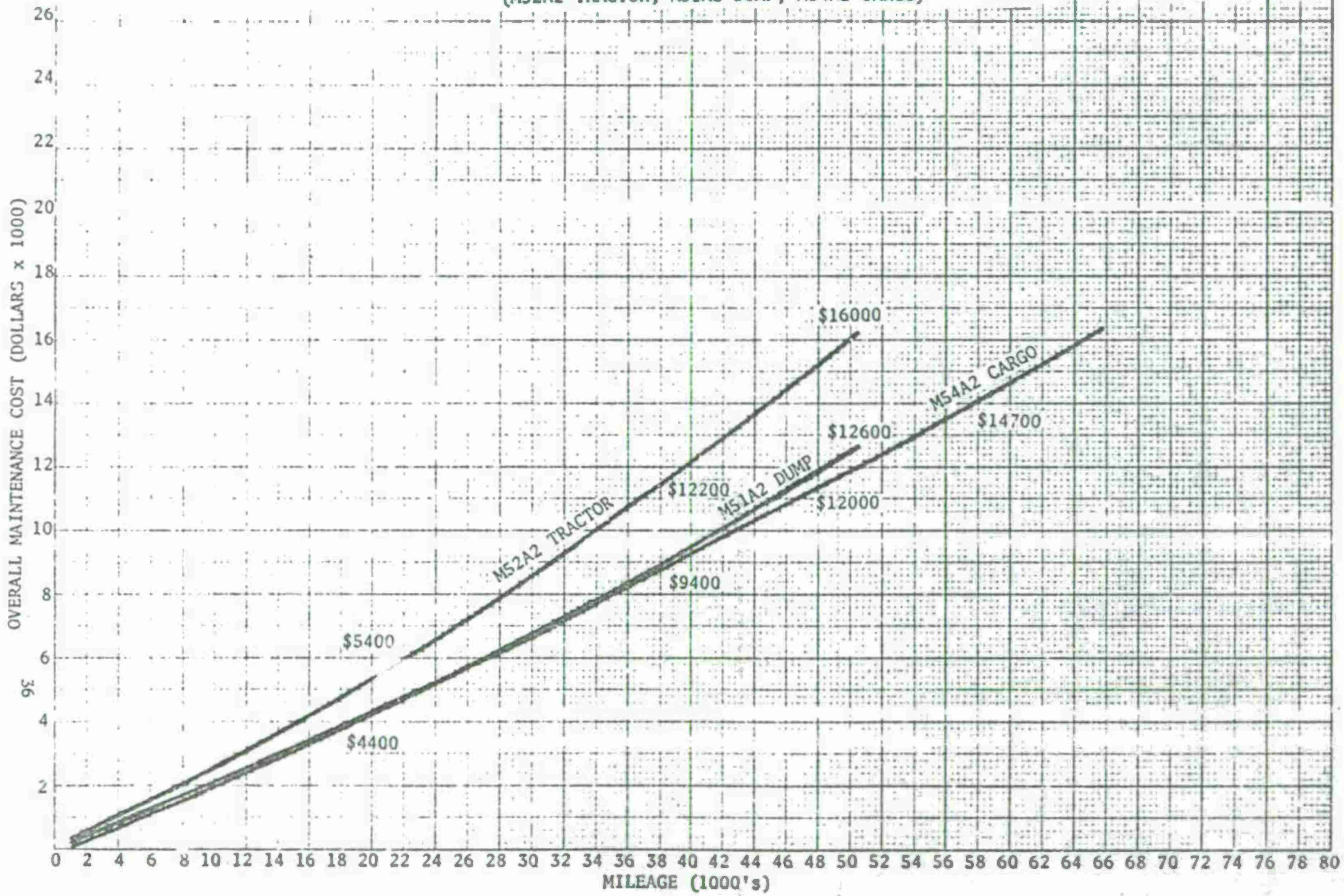


FIGURE 9.4

CUMULATIVE OVERALL MAINTENANCE COST FOR M39A2 5 Ton Trucks
(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)



The results of the analyses indicated above revealed the following:

1. The instantaneous maintenance cost (the maintenance cost per mile at a specific mileage) when excluding engine costs for all body types (cargo, dump or tractor) was found to be decreasing from 15.6¢ per mile at 1000 miles until the vehicle reached 40,000 miles at which point the cost essentially leveled off at 10.0¢ per mile and then remained approximately at this figure through 65,000 miles of usage.

2. The instantaneous maintenance cost attributed to engine replacement costs was found to be increasing with increasing vehicle usage for all three body types and in addition the rate of increase was found to be different for each body type. For example, the instantaneous maintenance cost derived from engine replacements for the tractor (the body type with the highest engine replacement costs) was noted to be increasing from 5¢ per mile at 1000 miles to near 30¢ per mile at 50,000 miles. For the dump truck, the engine associated instantaneous maintenance cost was noted to be increasing from 3¢ per mile at 1000 miles to 21¢ per mile at 50,000 miles while the cargo truck (the body type with the least engine replacement costs) was determined to be increasing from 4¢ per mile at 1000 miles to about 17¢ per mile at 50,000 miles. It should be noted that the engine costs presented are based on replacing the engine with a new engine whereas it is known that part of the time the engine is replaced with a rebuilt engine which may be less costly than a new engine. However, in order to provide a conservative or worst case cost picture all engine replacements were costed at the new engine price.

3. The instantaneous overall maintenance costs associated with all parts including the engine (see Figure 9.3) was also found to be increasing with increasing vehicle usage for all three body types and the rate of increase was determined to be different for each body type. For example, the tractor was determined to be increasing from approximately 23¢ per mile at 1000 miles to near 40¢ mile at 50,000 miles while the dump and cargo trucks were determined to be increasing from 20¢ and 21¢ per mile at 1000 miles to 31¢ and 27¢ per mile at 50,000 miles respectively.

4. As shown on the cumulative overall maintenance cost curves of Figure 9.4, the tractor is noted to have the highest cumulative maintenance cost over the 50,000 miles of usage ($16,000). This compares with $12,600 for the dump truck and $12,000 for the cargo truck over this same mileage interval.

As stated earlier, the primary objective of this cost analysis was to determine the mileage at which the overall system cost to the Army is at a minimum; i.e., the costs associated with procuring, shipping, and maintaining the truck are minimized. Utilizing the overall instantaneous maintenance costs developed and the truck rollaway cost (includes acquisition costs, engineering and tooling costs, administrative costs, first destination charge and applicable second destination charge) of \$24,700, an average system cost as a function of mileage was determined. A plot of the average system cost as a function of mileage is shown on Figure 9.5. As noted on this figure, the minimum of the average system cost for all three vehicles (tractor, dump and cargo truck) is indicated to be beyond 60,000 miles although at 60,000 miles the average system cost is found to be near its minimum. For example, at 60,000 miles, the average system cost is noted to be decreasing only by a value of 0.5¢ or less per mile for each additional 1000 miles of usage (through an extrapolated 70,000 miles of usage). Based on these figures, the economic life of these trucks was considered to be 60,000 miles (see Appendix for assumptions related to the economic replacement policy).

10. PERFORMANCE ANALYSIS

10.1 Unscheduled Maintenance Action Analysis.

As indicated earlier, in place of a reliability failure analysis, an analysis of all unscheduled maintenance actions was carried out due to the difficulty in determining if an unscheduled maintenance action was in fact a reliability failure. In analyzing the unscheduled maintenance actions, a system Weibull failure rate function was applied; i.e.,

$$r(t) = \lambda\beta t^{\beta-1} \quad t>0,\lambda>0,\beta>0$$

where λ = scale parameter

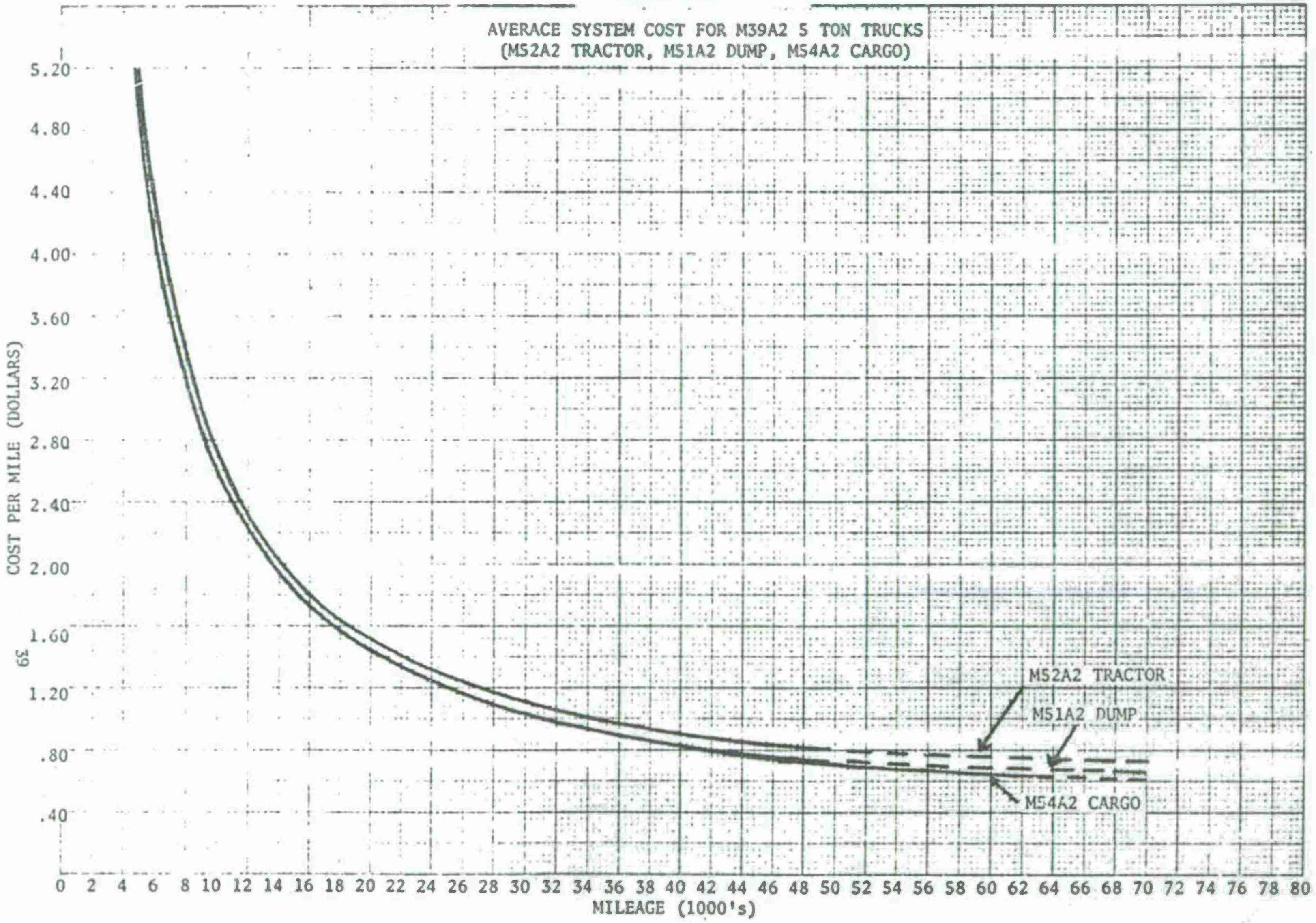
β = shape parameter

This function assumes that the probability that a vehicle will have an unscheduled maintenance action at mileage t is proportional to r(t) and independent of the unscheduled maintenance action history of the system prior to t. This definition differs from the usual definition which states that the probability of an unscheduled maintenance action at mileage t is also proportional to r(t) but conditioned on no unscheduled maintenance actions prior to t. The former definition applies to repairable systems whereas the latter definition does not.

From this function, the probability that a vehicle with mileage t will complete an additional s miles without undergoing an unscheduled maintenance action (as determined by a nonhomogeneous Poisson process) is

$$P(s/t) = e^{-\lambda(t+s)^{\beta}+\lambda t^{\beta}}$$

FIGURE 9.5



AVERAGE SYSTEM COST FOR M39A2 5 TON TRUCKS
(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)
COST PER MILE (DOLLARS)
5.20
4.80
4.40
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
.80
.40
M52A2 TRACTOR
M51A2 DUMP
M54A2 CARGO
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80
MILEAGE (1000's)

where $\lambda(t+s)^{\beta}-\lambda t^{\beta}$ is the expected number of unscheduled maintenance actions for a vehicle during the mileage interval (t, t+s).

Noted below are the maximum likelihood estimates (MLE) for the system Weibull failure rate function determined for each body type. These estimates apply only through the mileages indicated since the failure rate function was essentially constant beginning with this mileage.

Body Type	Mileage	$\hat{\lambda}$	$\hat{\beta}$
M52A2 Tractor	26,000	.03[illegible]9	.6442
M51A2 Dump	40,000	.0119	.7682
M54A2 Cargo	34,000	.0239	.6969

The results of this analysis are shown in Table 10.1. Indicated in this table is the expected number of UMA's for the next 1000 miles of usage and the probability of completing 75 miles without a UMA for each 5000 mile interval from 0 to 50,000 for the tractor and dump truck and from 0 to 65,000 miles for the cargo truck. Goodness-of-fit criteria indicated that the data shown are based on a model that is noted to provide a good fit of the field data. The average probability of completing 75 miles without requiring an unscheduled maintenance action over the 0-50,000 mile interval is .91 for the tractor and dump truck while the average probability of completing 75 miles without requiring an unscheduled maintenance action for the cargo truck over the 0-65,000 mile interval is .92.

10.2 Inherent Readiness Analysis.

As with a reliability failure analysis, the determination of availability is normally based on failure data. For example, Inherent Availability (A_i) is normally defined as:

$$A_i = \frac{\text{MTBF}}{\text{MTBF+MTTR}}$$

where MTBF is the mean time between failures and MTTR is the mean time to repair.

As noted in previous sections of this report, unscheduled maintenance actions rather than failure data were available. Further, the TAERS data provided information on the mean man-hours to repair

TABLE 10.1

PROBABILITY OF COMPLETING 75 MILES
WITHOUT AN UNSCHEDULED MAINTENANCE ACTION
FOR M39A2 5 TON TRUCKS

(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)

	EXPECTED NUMBER OF UNSCHEDULED MAINTENANCE ACTIONS FOR THE NEXT 1000 MILES			PROBABILITY OF COMPLETING 75 MILES WITHOUT AN UNSCHEDULED MAINTENANCE ACTION		
MILEAGE	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO
0	2.9	2.4	2.9	.58	.58	.62
1000	1.6	1.7	1.8	.87	.87	.86
5000	1.0	1.2	1.2	.92	.91	.91
10000	0.8	1.1	1.0	.94	.92	.93
15000	0.7	1.0	0.9	.95	.93	.93
20000	0.6	0.9	0.8	.95	.93	.94
25000	0.6	0.9	0.8	.96	.94	.94
30000	0.6	0.8	0.7	.96	.94	.95
35000	0.6	0.8	0.7	.96	.94	.95
40000	0.6	0.8	0.7	.96	.94	.95
45000	0.6	0.8	0.7	.96	.94	.95
50000	0.6	0.8	0.7	.96	.94	.95
55000	-	-	0.7	-	-	.95
60000	-	-	0.7	-	-	.95
65000	-	-	0.7	-	-	.95
AVERAGE	-	-	-	.91	.91	.92

rather than the mean time to repair. The mean time to repair for a particular maintenance action could be less than the man-hours involved if two or more mechanics worked on a particular maintenance action. To utilize this data, however, to obtain an estimate of an availability statistic, one can determine the probability of a truck not undergoing active repair due to any unscheduled maintenance action when called upon to operate at a random point in time (Inherent Readiness) and this is given by the following expression:

$$R_i = \frac{MTBUMA}{MTBUMA+MMHTR}$$

where MTBUMA is the mean time between unscheduled maintenance actions (assuming an average speed of 20 mph) and MMHTR is the mean man-hours to repair. It should be noted that the Inherent Readiness parameter is a lower bound on an Inherent Availability value, i.e., if all unscheduled maintenance actions were reliability failures and if no more than one mechanic ever worked on a maintenance action then the mean man-hours to repair would be equivalent to the mean time to repair and $R_i = A_i$.

The results of this analysis are shown in Table 10.2. Indicated in this table are the mean miles between unscheduled maintenance actions (MMBUMA) and Inherent Readiness (R_i) values for 1000 mile intervals through 50,000 miles for the M52A2 Tractor and M51A2 Dump Truck and through 65,000 miles for the M54A2 Cargo Truck. As can be readily observed, no degradation in the Inherent Readiness has occurred with any of the body types as the vehicles increased in mileage. One interesting sidelight noted in this table is that the lowest MMBUMA and R_i values occurs during the initial 1000 miles of usage. This, however, is probably due to quality control problems that may occur with a new vehicle. In summary, it is noted that over the mileages studied (50,000 miles for the tractor and dump truck and 65,000 miles for the cargo truck) the MMBUMA and R_i values are 1330 miles and .92, respectively for the M52A2 Tractor, 1025 miles and .93, respectively for the M51A2 Dump Truck, and 1161 miles and .92, respectively for the M54A2 Cargo Truck.

The Inherent Readiness parameter discussed above is noted to be the probability that the truck is not undergoing active repair due to an unscheduled maintenance action when called upon to operate at any point in time. This parameter, thus, does not include vehicle logistic downtime, i.e., downtime associated with obtaining and waiting for parts. This was not included in the study as it was not readily available in the TAERS data. In comparing the Inherent Readiness estimates with similar estimates obtained from a recent AMC Materiel

TABLE 10.2

PROBABILITY OF TRUCK NOT UNDERGOING ACTIVE REPAIR
DUE TO AN UNSCHEDULED MAINTENANCE ACTION AT ANY
POINT IN TIME (INHERENT READINESS) FOR M39A2 5 TON TRUCKS

(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)

	MEAN MILES BETWEEN UNSCHEDULED MAINT. ACTIONS* (MMBUMA)			INHERENT READINESS (R_i)		
MILEAGE INTERVAL (1000's)	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO
0-1	345	418	340	.75	.84	.77
4-5	914	770	769	.89	.91	.88
9-10	1193	916	966	.91	.92	.90
14-15	1387	1010	1098	.92	.93	.91
19-20	1541	1082	1201	.93	.93	.92
24-25	1671	1141	1287	.93	.94	.93
29-30	1719	1191	1362	.94	.94	.93
34-35	1719	1235	1428	.94	.94	.93
39-40	1719	1275	1428	.94	.94	.94
44-45	1719	1282	1428	.94	.94	.94
49-50	1719	1282	1428	.94	.94	.94
54-55	-	-	1428	-	-	.94
59-60	-	-	1428	-	-	.94
64-65	-	-	1428	-	-	.94
OVERALL	1330	1025	1161	.92	.93	.92

*THE MMBUMA IS DEFINED TO BE THE LENGTH OF THE MILEAGE INTERVAL (1000 MILES) DIVIDED BY THE MEAN NUMBER OF UNSCHEDULED MAINTENANCE ACTIONS FOR A VEHICLE DURING THE MILEAGE INTERVAL.

Readiness Report the Inherent Readiness values compare favorably with the AMC Readiness Report values. For example, the Inherent Readiness value of .92 for the M54A2 Cargo Truck as obtained in this study converts to a .96 value when transforming the man-hour indications to clock-hour indications (a conversion factor of 1.8 man-hours = 1 clock hour is used). This .96 readiness value is thus determined to be the same as the AMC Readiness Report value of .96. The AMC report further notes that when logistic downtime is considered in the availability parameter, the availability of this vehicle is indicated to be .85.

10.3 Maintainability Analysis.

The object of this analysis was to determine if the man-hours required for maintenance were changing as the truck increased in mileage. In addition, a parts replacement analysis was conducted. This latter analysis consisted of the following: (1) major component replacements as a function of mileage (engine, axles, differential and transfer case), (2) high cost parts (in excess of $100.00) replacements, (3) ten most frequently replaced parts and (4) determination of the number of replacements for all vehicle parts. These analyses were carried out separately for each of the three 5 ton vehicles studied (M52A2 Tractor, M51A2 Dump Truck and M54A2 Cargo Truck).

Shown in Tables 10.3, 10.4 and 10.5 are summaries of the man-hour data obtained for the tractor, dump and cargo trucks included in the study. Of particular interest in these tables are the average man-hours required per truck per 1000 miles, the average man-hours required per maintenance action and the maintenance support index (number of maintenance man-hours required per hour of truck operation); all reported by 1000 mile intervals. These data are shown through 50,000 miles for the tractor and dump truck and through 65,000 miles for the cargo truck.

As can be readily observed in Tables 10.3, 10.4 and 10.5, the average maintenance man-hours required per truck per 1000 miles (and subsequently the maintenance support index) was noted to be at its highest during the initial 1000 miles of usage (37.7, 26.8 and 33.7 man-hours for the tractor, dump and cargo trucks, respectively). This is believed due to two primary reasons: (1) the relatively large number of man-hours associated with the processing-in of a new vehicle and (2) initial quality control problems that occur with a new vehicle. However, the maintenance man-hours required are noted to decrease from the levels required during the initial 1000 miles of usage to about 10.0 man-hours at 5,000 miles with the number of man-hours required for maintenance remaining relatively stable at or near 10.0 man-hours through at least 50,000 miles. Thus, over the initial 50,000 miles, the average man-hours required for maintenance per truck per 1000 miles was 9.2 and 7.7 man-hours for the tractor and dump trucks respectively, while for the cargo truck over the initial 65,000 miles, the average man-hours required for maintenance per truck per 1000 miles was 9.5 man-hours. The average

TABLE 10.3

MAINTAINABILITY DATA FOR THE M52A2 5 TON TRACTOR

MILEAGE INTERVAL (1000's)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. & UNSCH.)	NO. OF MAN-HOURS	AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES	AVERAGE MAN-HOURS PER MAINT. ACTION	MAINT.* SUPPORT INDEX
0- 1	1034	17455	38976	37.7	2.2	.75
1- 2	1212	8625	23192	19.1	2.7	.38
2- 3	1103	4762	15159	13.7	3.2	.27
3- 4	1016	4292	12473	12.3	2.9	.25
4- 5	948	3378	10280	10.8	3.0	.22
5- 6	875	2339	6250	7.1	2.7	.14
6- 7	815	2768	8274	10.1	3.0	.20
7- 8	776	2350	6324	8.2	2.7	.16
8- 9	738	2275	6595	8.9	2.9	.18
9-10	692	2396	7413	10.7	3.1	.21
10-11	667	2110	5706	8.6	2.7	.17
11-12	628	1759	4838	7.7	2.8	.15
12-13	592	2068	5775	9.8	2.8	.20
13-14	547	1749	5068	9.3	2.9	.19
14-15	519	1575	4165	8.0	2.6	.16
15-16	482	1584	4488	9.3	2.8	.19
16-17	447	1510	4637	10.4	3.1	.21
17-18	422	1333	3709	8.8	2.8	.18
18-19	387	1262	3514	9.1	2.8	.18
19-20	363	1184	3415	9.4	2.9	.19
20-21	330	1149	2771	8.4	2.4	.17
21-22	296	909	2395	8.1	2.6	.16
22-23	262	684	1856	7.1	2.7	.14
23-24	234	792	1849	7.9	2.3	.16
24-25	222	678	1987	9.0	2.9	.18
25-26	210	713	1905	9.1	2.7	.18
26-27	195	574	1469	7.5	2.6	.15
27-28	166	418	1162	7.0	2.8	.14
28-29	147	445	1055	7.2	2.4	.14
29-30	133	483	1044	7.9	2.2	.16
30-31	122	514	1416	11.6	2.7	.23
31-32	102	381	1012	9.9	2.7	.20
32-33	92	332	649	7.1	2.0	.14
33-34	83	265	631	7.6	2.4	.15
34-35	75	202	459	6.1	2.3	.12
35-36	70	239	597	8.5	2.5	.17
36-37	64	217	501	7.8	2.3	.16
37-38	56	236	554	9.9	2.4	.20
38-39	45	101	179	4.0	1.8	.08
39-40	40	74	188	4.7	2.5	.09
40-41	35	68	177	5.0	2.6	.10
41-42	30	93	193	6.4	2.1	.13
42-43	26	93	246	9.5	2.7	.19
43-44	21	63	195	9.3	3.1	.19
44-45	18	47	103	5.7	2.2	.11
45-46	15	71	86	5.7	1.2	.11
46-47	13	68	179	13.7	2.6	.27
47-48	13	42	87	6.7	2.1	.13
48-49	13	30	79	6.1	2.6	.12
49-50	9	24	39	4.3	1.6	.09

*INDICATES NUMBER OF MAINTENANCE MAN-HOURS REQUIRED PER HOUR OF TRUCK OPERATION (ASSUMING AN AVERAGE SPEED OF 20 MPH)

SUMMARY

1. AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES: 9.2

2. AVERAGE MAN-HOURS PER MAINTENANCE ACTION: 2.6

3. AVERAGE MAINTENANCE SUPPORT INDEX: .18

TABLE 10.4

MAINTAINABILITY DATA FOR THE M51A2 5 TON DUMP TRUCK

MILEAGE INTERVAL (1000's)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. & UNSCH.)	NO. OF MAN-HOURS	AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES	AVERAGE MAN-HOURS PER MAINT. ACTION	MAINT.* SUPPORT INDEX
0- 1	975	10508	26111	26.8	2.5	.54
1- 2	1194	5868	13547	11.3	2.3	.23
2- 3	1070	4982	11800	11.0	2.4	.22
3- 4	945	4490	10233	10.8	2.3	.22
4- 5	873	3475	8490	9.7	2.4	.19
5- 6	842	3143	6997	8.3	2.2	.17
6- 7	807	3098	8107	10.1	2.6	.20
7- 8	771	2495	6221	8.1	2.5	.16
8- 9	734	2760	7621	10.4	2.8	.21
9-10	683	2319	5688	8.3	2.5	.17
10-11	631	2188	5677	9.0	2.6	.18
11-12	597	2027	4824	8.1	2.4	.16
12-13	553	1947	5576	10.1	2.9	.20
13-14	498	1654	3604	7.2	2.2	.14
14-15	453	1456	3179	7.0	2.2	.14
15-16	413	1336	3118	7.6	2.3	.15
16-17	373	1248	2912	7.8	2.3	.16
17-18	345	1044	2144	6.2	2.1	.12
18-19	305	1099	2640	8.7	2.4	.17
19-20	275	721	1677	6.1	2.3	.12
20-21	257	809	1943	7.6	2.4	.15
21-22	235	704	1346	5.7	1.9	.11
22-23	217	624	1389	6.4	2.2	.13
23-24	197	624	1149	5.8	1.8	.12
24-25	179	426	948	5.3	2.2	.11
25-26	161	462	1099	6.8	2.4	.14
26-27	144	468	1237	8.6	2.6	.17
27-28	127	438	1171	9.2	2.7	.18
28-29	113	373	806	7.1	2.2	.14
29-30	103	257	502	4.9	2.0	.10
30-31	94	265	604	6.4	2.3	.13
31-32	83	274	757	9.1	2.8	.18
32-33	74	165	492	6.7	3.0	.13
33-34	65	168	501	7.7	0	.15
34-35	56	149	355	6.3	2.4	.13
35-36	53	159	371	7.0	2.3	.14
36-37	46	90	199	4.3	2.2	.09
37-38	43	106	268	6.2	2.5	.12
38-39	38	115	339	8.9	3.0	.18
39-40	34	110	261	7.7	2.4	.15
40-41	29	61	142	4.9	2.3	.10
41-42	24	63	134	5.6	2.1	.11
42-43	23	38	128	5.5	3.4	.11
43-44	20	50	220	11.0	4.4	.22
44-45	16	23	55	3.4	2.4	.07
45-46	15	14	64	4.3	4.6	.09
46-47	14	28	28	2.0	1.0	.04
47-48	13	21	59	4.5	2.8	.09
48-49	10	26	51	5.1	2.0	.10
49-50	9	32	81	9.0	2.5	.18

*INDICATES NUMBER OF MAINTENANCE MAN-HOURS REQUIRED PER HOUR OF TRUCK OPERATION (ASSUMING AN AVERAGE SPEED OF 20 MPH)

SUMMARY

1. AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES: 7.7
2. AVERAGE MAN-HOURS PER MAINTENANCE ACTION: 2.5
3. AVERAGE MAINTENANCE SUPPORT INDEX: .15

TABLE 10.5

MAINTAINABILITY DATA FOR THE M54A2 5 TON CARGO TRUCK

MILEAGE INTERVAL (1000's)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. & UNSCH.)	NO. OF MAN-HOURS	AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES	AVERAGE MAN-HOURS PER MAINT. ACTION	MAINT.* SUPPORT INDEX
0- 1	643	9081	21637	33.7	2.4	.67
1- 2	821	5558	13839	16.9	2.5	.34
2- 3	768	4026	10346	13.5	2.6	.27
3- 4	687	3588	8904	13.0	2.5	.26
4- 5	600	2702	6769	11.3	2.5	.23
5- 6	520	2354	6219	12.0	2.6	.24
6- 7	440	1899	4759	10.8	2.5	.22
7- 8	391	1346	3002	7.7	2.2	.15
8- 9	347	1315	3102	8.9	2.4	.18
9-10	315	1126	2590	8.2	2.3	.16
10-11	289	1047	2581	8.9	2.5	.18
11-12	261	902	1975	7.6	2.2	.15
12-13	232	733	2135	9.2	2.9	.18
13-14	209	566	1211	5.8	2.1	.12
14-15	187	586	1316	7.0	2.3	.14
15-16	175	508	1335	7.6	2.6	.15
16-17	163	421	1029	6.3	2.4	.13
17-18	147	388	802	5.5	2.1	.11
18-19	131	471	1219	9.3	2.6	.19
19-20	117	326	820	7.0	2.5	.14
20-21	108	239	657	6.1	2.8	.12
21-22	99	365	1010	10.2	2.8	.20
22-23	90	294	838	9.3	2.9	.19
23-24	82	305	963	11.7	3.2	.23
24-25	73	254	579	7.9	2.3	.16
25-26	69	218	558	8.1	2.6	.16
26-27	65	193	553	8.5	2.9	.17
27-28	63	221	643	10.2	2.9	.20
28-29	60	143	397	6.6	2.8	.13
29-30	53	149	337	6.4	2.3	.13
30-31	53	158	510	9.6	3.2	.19
31-32	55	155	374	6.8	2.4	.14
32-33	52	213	568	10.9	2.7	.22
33-34	50	150	331	6.6	2.2	.13
34-35	47	135	229	4.9	1.7	.10
35-36	47	191	515	11.0	2.7	.22
36-37	45	136	277	6.2	2.0	.12
37-38	45	169	437	9.7	2.6	.19
38-39	45	199	493	11.0	2.5	.22
39-40	43	218	589	13.7	2.7	.27
40-41	43	196	455	10.6	2.3	.21
41-42	46	232	552	12.0	2.4	.24
42-43	47	181	430	9.1	2.4	.18
43-44	45	247	601	13.4	2.4	.27
44-45	44	139	459	10.4	3.3	.21
45-46	45	165	368	8.2	2.2	.16
46-47	44	164	391	8.9	2.4	.18
47-48	45	193	536	11.9	2.8	.24
48-49	43	171	529	12.3	3.1	.25
49-50	41	146	404	9.9	2.8	.20
50-51	40	129	322	8.1	2.5	.16
51-52	38	122	267	7.0	2.2	.14
52-53	36	140	379	10.5	2.7	.21
53-54	34	63	187	5.5	3.0	.11
54-55	33	103	293	8.9	2.8	.18
55-56	31	124	369	11.9	3.0	.24
56-57	31	58	133	4.3	2.3	.09
57-58	31	97	344	11.1	3.5	.22
58-59	28	89	212	7.6	2.4	.15
59-60	24	82	257	10.7	3.1	.21
60-61	24	46	118	4.9	2.6	.10
61-62	22	73	225	10.2	3.1	.20
62-63	17	42	104	6.1	2.5	.12
63-64	14	16	55	3.9	3.4	.08
64-65	9	28	120	13.3	4.3	.27

TABLE 10.5 (Cont'd)

*INDICATES NUMBER OF MAINTENANCE MAN-HOURS REQUIRED PER HOUR OF TRUCK OPERATION (ASSUMING AN AVERAGE SPEED OF 20 MPH)

SUMMARY

1. AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES : 9.5

2. AVERAGE MAN-HOURS PER MAINTENANCE ACTION : 2.6

3. AVERAGE MAINTENANCE SUPPORT INDEX : .19

maintenance support index for these mileages was noted to be .18, .15 and .19 for the tractor, dump and cargo trucks respectively.

In analyzing the average man-hours required per maintenance action, it was noted that the average tractor, dump and cargo truck required maintenance on an unscheduled basis an average of 37.6, 48.8 and 56.0 times, respectively over the mileage accumulation periods noted above and during each of these maintenance stops the tractor, dump and cargo trucks had on the average 2.3, 1.8 and 1.9 different components, respectively repaired, replaced or adjusted. The number of man-hours utilized for each of these component actions averaged 2.6 man-hours for the tractor and cargo truck and 2.5 man-hours for the dump truck. Shown in Tables 10.3, 10.4 and 10.5 are the maintenance man-hours required for each maintenance action by 1000 mile intervals.

As noted above, an analysis of major component replacements (engine, transfer case, differential and axle) for all three vehicles was made. This analysis consisted of determining for these components, the number and percent replaced by increasing 1000 mile intervals (see Tables 10.6, 10.7 and 10.8). The object of this analysis was to determine if any of these major components exhibited wearout characteristics at a particular mileage or mileage interval. The results of this analysis indicated that the engine was the only major component to exhibit wearout characteristics with increasing mileage of the vehicle. This was noted with all three vehicle body types. Shown on Figure 10.1 is a plot of the cumulative number of engine replacements that may be expected with the average 5 ton tractor, dump and cargo truck. This plot shows that the average M52A2 tractor will have its first engine replacement at 22,000 miles, the second engine replacement at 36,000 miles and the third engine replacement at 48,000 miles. The average M51A2 dump truck was noted to have its first engine replacement at 30,000 miles and the second engine replacement at 48,000 miles. The average M54A2 cargo truck exhibited its first engine replacement at 31,000 miles and its second engine replacement at 52,000 miles. As can be seen, the engine wore out more quickly in the tractor than in the dump or cargo truck. This is evidenced by the fact that during the initial 50,000 miles of operation, the tractor required approximately three engine replacements while the dump and cargo trucks required approximately two engine replacements. A summary of the performance of these major components indicated that during the initial 50,000 miles of operation of the tractor, 100% of the engines would be replaced, 23.5% of the transfer cases would be replaced, .9% of the differentials would be replaced and 2.0% of the axles would be replaced. A summary of the performance of the major components for the dump truck during the initial 50,000 miles of operation revealed that 100% of the engines would be replaced, 21.4% of the transfer cases would be replaced and 4.8% of the axles would be replaced. With the cargo truck, the performance summary indicated that over the initial 65,000 miles, 100% of the engines would be replaced, 16.2% of the transfer cases would be replaced, .2% of the differentials would be replaced and 10.0% of the

TABLE 10.6

MAJOR COMPONENT REPLACEMENTS FOR M52A2 5 TON TRACTOR

MILEAGE INTERVAL (1000's)	AVG. NO. OF VEHICLES	ENGINE NO. REPLACED	ENGINE % REPLACED	TRANSFER CASE NO. REPLACED	TRANSFER CASE % REPLACED	DIFFERENTIAL NO. REPLACED	DIFFERENTIAL % REPLACED	AXLE NO. REPLACED	AXLE % REPLACED
0- 1	1034	18	1.7	1	.1	1	.1	2	.2
1- 2	1212	21	1.7	3	.2	0	0	1	.1
2- 3	1103	15	1.4	3	.3	0	0	1	.1
3- 4	1016	23	2.3	0	0	0	0	0	0
4- 5	948	23	2.4	3	.3	0	0	0	0
5- 6	875	20	2.3	1	.1	0	0	2	.2
6- 7	815	37	4.5	1	.1	0	0	0	0
7- 8	776	36	4.6	0	0	0	0	1	.1
8- 9	738	34	4.6	1	.1	0	0	0	0
9-10	692	31	4.5	2	.3	0	0	1	.1
10-11	667	30	4.5	1	.1	0	0	0	0
11-12	628	30	4.8	1	.2	0	0	2	.3
12-13	592	31	5.2	3	.5	0	0	0	0
13-14	547	25	4.6	1	.2	0	0	0	0
14-15	519	34	6.6	0	0	0	0	0	0
15-16	482	43	8.9	1	.2	0	0	0	0
16-17	447	28	6.3	2	.4	0	0	0	0
17-18	422	31	7.3	3	.7	0	0	0	0
18-19	387	26	6.7	2	.5	0	0	0	0
19-20	363	20	5.5	3	.8	0	0	1	.3
20-21	330	25	7.6	0	0	0	0	1	.3
21-22	296	17	5.7	0	0	0	0	1	.3
22-23	262	10	3.8	2	.8	0	0	0	0
23-24	234	18	7.7	3	1.3	0	0	0	0
24-25	222	15	6.8	0	0	0	0	0	0
25-26	210	14	6.7	0	0	0	0	0	0
26-27	195	10	5.1	4	2.1	0	0	0	0
27-28	166	7	4.2	1	.6	0	0	0	0
28-29	147	6	4.1	0	0	0	0	0	0
29-30	133	8	6.0	1	.8	1	.8	0	0
30-31	122	13	10.7	0	0	0	0	0	0
31-32	102	10	9.8	0	0	0	0	0	0
32-33	92	10	10.9	0	0	0	0	0	0
33-34	83	7	8.4	1	1.2	0	0	0	0
34-35	75	5	6.7	1	1.3	0	0	0	0
35-36	70	5	7.1	0	0	0	0	0	0
36-37	64	3	4.7	0	0	0	0	0	0
37-38	56	7	12.5	0	0	0	0	0	0
38-39	45	1	2.2	1	2.2	0	0	0	0
39-40	40	0	0	0	0	0	0	0	0
40-41	35	1	2.9	0	0	0	0	0	0
41-42	30	2	6.7	1	3.3	0	0	0	0
42-43	26	1	3.8	0	0	0	0	0	0
43-44	21	1	4.8	1	4.8	0	0	0	0
44-45	18	0	0	0	0	0	0	0	0
45-46	15	0	0	0	0	0	0	0	0
46-47	13	1	7.7	0	0	0	0	0	0
47-48	13	1	7.7	0	0	0	0	0	0
48-49	13	1	7.7	0	0	0	0	0	0
49-50	9	0	0	0	0	0	0	0	0

SUMMARY

DURING THE FIRST 50,000 MILES,

(1) 100% OF THE ENGINES WERE REPLACED.

(2) 23.5% OF THE TRANSFER CASES WERE REPLACED.

(3) .9% OF THE DIFFERENTIALS WERE REPLACED.

(4) 2.0% OF THE AXLES WERE REPLACED.

TABLE 10.7

MAJOR COMPONENT REPLACEMENTS FOR M51A2 5 TON DUMP TRUCK

MILEAGE INTERVAL (1000's)	AVG. NO. OF VEHICLES	ENGINE NO. REPLACED	ENGINE % REPLACED	TRANSFER CASE NO. REPLACED	TRANSFER CASE % REPLACED	DIFFERENTIAL NO. REPLACED	DIFFERENTIAL % REPLACED	AXLE NO. REPLACED	AXLE % REPLACED
0- 1	975	9	.9	1	.1	0	0	0	0
1- 2	1194	11	.9	0	0	0	0	1	.1
2- 3	1070	10	.9	5	.5	0	0	1	.1
3- 4	945	6	.6	2	.2	0	0	1	.1
4- 5	873	25	2.9	2	.2	0	0	5	.6
5- 6	842	15	1.8	0	0	0	0	0	0
6- 7	807	19	2.4	2	.2	0	0	1	.1
7- 8	771	18	2.3	0	0	0	0	1	.1
8- 9	734	21	2.9	2	.3	0	0	2	.3
9-10	683	19	2.8	0	0	0	0	1	.1
10-11	631	18	2.9	0	0	0	0	2	.3
11-12	597	30	5.0	4	.7	0	0	1	.2
12-13	553	21	3.8	5	.9	0	0	2	.4
13-14	498	19	3.8	1	.2	0	0	0	0
14-15	453	19	4.2	1	.2	0	0	0	0
15-16	413	14	3.4	3	.7	0	0	1	.2
16-17	373	10	2.7	1	.3	0	0	1	.3
17-18	345	13	3.8	0	0	0	0	0	0
18-19	305	14	4.6	4	1.3	0	0	1	.3
19-20	275	10	3.6	1	.4	0	0	0	0
20-21	257	10	3.9	0	0	0	0	0	0
21-22	235	10	4.3	0	0	0	0	0	0
22-23	217	7	3.2	2	.9	0	0	0	0
23-24	197	6	3.0	0	0	0	0	0	0
24-25	179	5	2.8	0	0	0	0	0	0
25-26	161	12	7.5	0	0	0	0	0	0
26-27	144	7	4.9	0	0	0	0	0	0
27-28	127	9	7.1	0	0	0	0	2	1.6
28-29	113	6	5.3	0	0	0	0	0	0
29-30	103	5	4.9	0	0	0	0	0	0
30-31	94	3	3.2	0	0	0	0	0	0
31-32	83	3	3.6	0	0	0	0	0	0
32-33	74	3	4.1	0	0	0	0	0	0
33-34	65	3	4.6	0	0	0	0	0	0
34-35	56	2	3.6	1	1.8	0	0	0	0
35-36	53	3	5.7	2	3.8	0	0	0	0
36-37	46	3	6.5	0	0	0	0	0	0
37-38	43	0	0	0	0	0	0	0	0
38-39	38	3	7.9	0	0	0	0	0	0
39-40	34	2	5.9	0	0	0	0	0	0
40-41	29	2	6.9	0	0	0	0	0	0
41-42	24	0	0	0	0	0	0	0	0
42-43	23	2	8.7	2	8.7	0	0	0	0
43-44	20	0	0	0	0	0	0	0	0
44-45	16	1	6.2	0	0	0	0	0	0
45-46	15	1	6.7	0	0	0	0	0	0
46-47	14	0	0	0	0	0	0	0	0
47-48	13	1	7.7	0	0	0	0	0	0
48-49	10	1	10.0	0	0	0	0	0	0
49-50	9	1	11.1	0	0	0	0	0	0

SUMMARY

DURING THE FIRST 50,000 MILES,

(1) 100% OF THE ENGINES WERE REPLACED.

(2) 21.4% OF THE TRANSFER CASES WERE REPLACED.

(3) 0% OF THE DIFFERENTIAL WERE REPLACED.

(4) 4.8% OF THE AXLES WERE REPLACED.

TABLE 10.8

MAJOR COMPONENT REPLACEMENT FOR M54A2 5 TON CARGO TRUCK

MILEAGE INTERVAL (1000's)	AVG. NO. OF VEHICLES	ENGINE		TRANSFER CASE		DIFFERENTIAL		AXLE	
		NO. REPLACED	% REPLACED	NO. REPLACED	% REPLACED	NO. REPLACED	% REPLACED	NO. REPLACED	% REPLACED
0- 1	643	8	1.2	3	.5	0	0	2	.3
1- 2	821	8	1.0	2	.2	0	0	0	0
2- 3	768	8	1.0	0	0	0	0	2	.3
3- 4	687	11	1.6	1	.1	0	0	1	.1
4- 5	600	15	2.5	2	.3	0	0	0	0
5- 6	520	16	3.1	1	.2	1	.2	0	0
6- 7	440	6	1.4	2	.5	0	0	0	0
7- 8	391	7	1.8	0	0	0	0	1	.3
8- 9	347	10	2.9	1	.3	0	0	0	0
9-10	315	10	3.2	0	0	0	0	0	0
10-11	289	15	5.2	0	0	0	0	0	0
11-12	261	5	1.9	0	0	0	0	0	0
12-13	232	13	5.6	0	0	0	0	0	0
13-14	209	7	3.3	0	0	0	0	0	0
14-15	187	7	3.7	1	.5	0	0	0	0
15-16	175	11	6.3	0	0	0	0	0	0
16-17	163	4	2.5	1	.6	0	0	0	0
17-18	147	2	1.4	1	.7	0	0	0	0
18-19	131	4	3.1	0	0	0	0	0	0
19-20	117	5	4.3	0	0	0	0	1	.9
20-21	108	3	2.8	0	0	0	0	0	0
21-22	99	4	4.0	0	0	0	0	0	0
22-23	90	5	5.6	0	0	0	0	0	0
23-24	82	8	9.8	0	0	0	0	0	0
24-25	73	3	4.1	1	1.4	0	0	0	0
25-26	69	3	4.3	0	0	0	0	1	1.4
26-27	65	4	6.2	0	0	0	0	0	0
27-28	63	6	9.5	0	0	0	0	0	0
28-29	60	1	1.7	0	0	0	0	0	0
29-30	53	2	3.8	0	0	0	0	0	0
30-31	53	4	7.5	0	0	0	0	0	0
31-32	55	1	1.8	0	0	0	0	0	0
32-33	52	3	5.8	1	1.9	0	0	0	0
33-34	50	1	2.0	0	0	0	0	0	0
34-35	47	1	2.1	0	0	0	0	0	0
35-36	47	2	4.3	0	0	0	0	1	2.1
36-37	45	0	0	0	0	0	0	0	0
37-38	45	2	4.4	0	0	0	0	0	0
38-39	45	2	4.4	1	2.2	0	0	0	0
39-40	43	4	9.3	0	0	0	0	0	0
40-41	43	0	0	0	0	0	0	0	0
41-42	46	4	8.7	0	0	0	0	0	0
42-43	47	1	2.1	0	0	0	0	0	0
43-44	45	5	11.1	0	0	0	0	0	0
44-45	44	4	9.1	0	0	0	0	0	0
45-46	45	1	2.2	0	0	0	0	0	0
46-47	44	1	2.3	0	0	0	0	0	0
47-48	45	3	6.7	0	0	0	0	1	2.2
48-49	43	4	9.3	0	0	0	0	0	0
49-50	41	0	0	0	0	0	0	1	2.4
50-51	40	2	5.0	0	0	0	0	0	0
51-52	38	0	0	0	0	0	0	0	0
52-53	36	0	0	0	0	0	0	0	0
53-54	34	2	5.9	0	0	0	0	0	0
54-55	33	0	0	1	3.0	0	0	0	0
55-56	31	3	9.7	0	0	0	0	0	0
56-57	31	0	0	0	0	0	0	0	0
57-58	31	4	12.9	1	3.8	0	0	0	0
58-59	28	1	3.6	0	0	0	0	0	0
59-60	24	0	0	0	0	0	0	0	0
60-61	24	0	0	0	0	0	0	0	0
61-62	22	2	9.1	0	0	0	0	0	0
62-63	17	0	0	0	0	0	0	0	0
63-64	14	0	0	0	0	0	0	0	0
64-65	9	0	0	0	0	0	0	0	0

SUMMARY

DURING THE FIRST 65,000 MILES,

(1) 100% OF THE ENGINES WERE REPLACED.

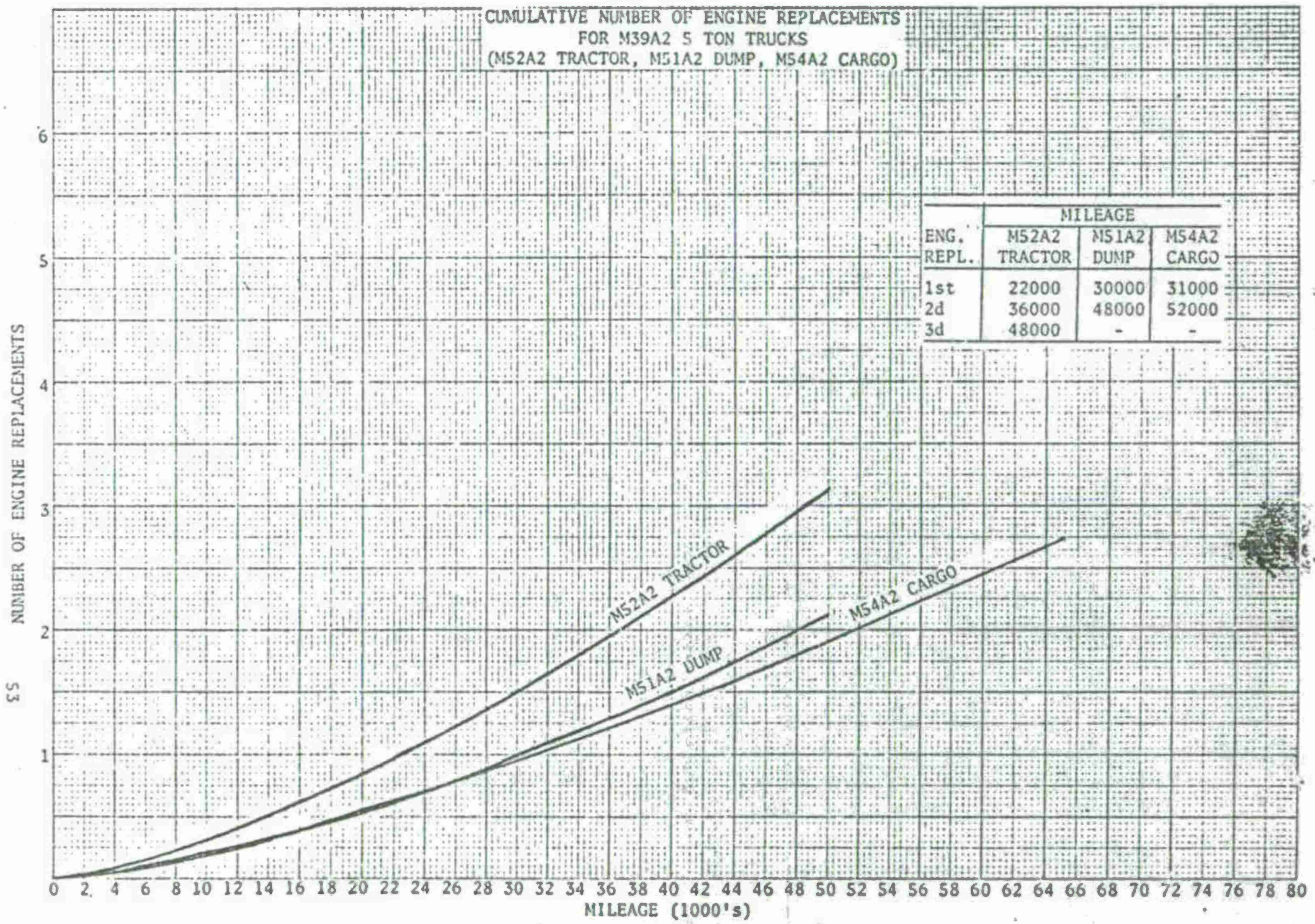
(2) 16.2% OF THE TRANSFER CASES WERE REPLACED.

(3) .2% OF THE DIFFERENTIALS WERE REPLACED.

(4) 10.0% OF THE AXLES WERE REPLACED.

BEE 20x20 TO INCH

FIGURE 10.1



	MILEAGE		
ENG. REPL.	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO
1st	22000	30000	31000
2d	36000	48000	52000
3d	48000	-	-

axles would be replaced.

In further analysis of parts replacements, a study of the high cost parts (in excess of $100.00) replacements was made. This analysis consisted of determining the number of replacements for all high cost components contained in the truck on an overall basis as well as by increasing 10,000 mile intervals (see Tables 10.9, 10.10 and 10.11). The object of this analysis was to determine which high cost components were being replaced most frequently and at what mileage intervals did these replacements occur. The results of this analysis indicated that the engine, starter, fuel pump and regulator were the most frequently replaced high cost components for all three body types. The results further indicated that the replacement of these components occurred at a relatively high rate throughout the mileage life of these vehicles. For example, on an overall basis, 26% of the starters were replaced. Dividing these replacements into mileage intervals shows 28% of the starter replacements in the 0-10,000 and 10,000-20,000 mile intervals, 23% of the starter replacements in the 20,000-30,000 mile interval and 11% of the starter replacements in the 30,000-40,000 mile interval. In the 40,000-50,000 mile interval no starter replacements occurred, however, only 19 vehicles were contained in this interval.

As indicated above, the parts analysis also included a determination of the ten most frequently replaced components in these trucks (see Tables 10.12, 10.13 and 10.14). As noted on these tables, the 10 most frequently replaced components are shown by 10,000 mile intervals as well as on an overall basis. This is done in order to determine if the components being replaced in the initial 10,000 mile interval are also being replaced in subsequent 10,000 mile intervals. For example, in Table 10.12 (M52A2 Tractor), the battery is noted to be first or second most frequently replaced component in all mileage intervals as well as on an overall basis. Also noted on these tables, alongside the replaced part, is the actual number of parts that were replaced. This value may be compared to the average number of vehicles in the interval, shown on the bottom of the table, so that the significance of the value can be determined. In addition to this list of 10 most frequently replaced parts, a list of the number of replacements for all components of the trucks included in the study is being compiled and will be published in a later report.

11. PROFILE OF AN AVERAGE M39A2 5 TON TRUCK

11.1 M52A2 Tractor.

The average M52A2 5 Ton Tractor during the initial 50,000 miles of usage will sustain a total maintenance cost (for both scheduled and unscheduled maintenance) of $16,000 or an average maintenance cost of 32¢ per mile. The average maintenance cost will be noted to be increasing during the initial 50,000 miles from 22¢ per mile at 1000 miles

TABLE 10.9

SUMMARY OF HIGH COST PART REPLACEMENTS

FOR M52A2 5 TON TRACTOR

(PARTS COSTING IN EXCESS OF $100.00)

PART FSN*	PART NOMENCLATURE	PART COST (DOLLARS)	NO. REPLACED	VEHICLE MILEAGE INTERVAL** (1000's OF MILES)				
				0-10	10-20	20-30	30-40	40-50
25107367608	FIFTH WHEEL ASSEMBLY	285	159	85	48	20	6	0
25107529313	WINDSHIELD ASSEMBLY	116	11	10	1	0	0	0
25109254543	FENDER, VEHICULAR	112	5	1	3	1	0	0
25200402318	PUMP ASSEMBLY	176	1	0	0	1	0	0
25200402340	PROPELLER SHAFT W/UNIVERSAL JT.	113	2	1	1	0	0	0
25200402341	PROPELLER SHAFT W/UNIVERSAL JT.	108	3	2	1	0	0	0
25202001280	AXLE	776	5	4	0	1	0	0
25206962955	TRANSFER ASSEMBLY W/FLANGES	567	48	15	17	11	3	2
25207336156	CARRIER, DIFFERENTIAL REAR	151	1	0	0	1	0	0
25207346970	DIFFERENTIAL, DRIVING AXLE, FRONT	383	3	1	0	1	1	0
25207346985	SHAFT	108	3	1	1	1	0	0
25209019682	PROPELLER SHAFT W/UNIVERSAL JT.	113	12	10	1	1	0	0
25307409395	HUB, CAPS, WHEEL	109	4	2	2	0	0	0
25403017269	KIT, HOT WATER	154	2	2	0	0	0	0
25403195931	HEATER ASSEMBLY, PERSONNEL, FRONT	129	1	1	0	0	0	0
25409530111	HEATER, COOLANT	150	20	10	6	4	0	0
25409603630	HEATER, VEHICULAR COOLANT	272	2	2	0	0	0	0
25906416405	WINCH ASSEMBLY	412	13	10	3	0	0	0
25907411122	WINCH ASSEMBLY	631	1	0	1	0	0	0
28050402204	CYLINDER HEAD, GASOLINE	290	3	0	2	1	0	0
28057376346	MANIFOLD, EXHAUST	224	1	0	1	0	0	0
28057409968	HEAD ASSEMBLY, CYLINDER	232	3	3	0	0	0	0
28150748919	HEAD GASKET SET	111	123	70	42	11	0	0
28152395819	ENGINE AND CONTAINER	3300	755	258	298	130	61	8
29107595410	PUMP, FUEL	329	351	195	93	49	8	0
29108510484	TANK, FUEL, ENGINE	117	15	6	6	2	0	1
29109086319	HEAD ASSEMBLY, FUEL INJECTOR	129	11	7	4	0	0	0
29109086320	PUMP, FUEL	330	66	18	26	14	8	0
29202266545	STARTER, ENGINE, ELECTRICAL	103	318	177	98	35	8	0
29203354264	REGULATOR, ENGINE GENERATOR	125	354	260	65	24	4	1
29207524474	GENERATOR, ENGINE ACCESSORY	134	2	2	0	0	0	0
29208188635	GENERATOR, ENGINE	213	2	0	1	1	0	0
29209747626	STARTER, ENGINE, ELECTRICAL	124	139	85	38	16	0	0
29305637235	RADIATOR, ENGINE COOLANT	108	39	32	5	1	1	0
29307375656	RADIATOR ASSEMBLY	151	195	84	75	26	9	1
29900748930	TURBO-CHARGER, COMPRESSION IGN	295	49	22	18	8	0	1
29909679909	TURBOCHARGER	283	59	22	18	14	5	0
45241607504	COCK	150	1	1	0	0	0	0
59503229448	PERSONNEL HEATER	131	2	2	0	0	0	0

*THE PARTS LISTED IN THE TABLE ARE ORDERED BY PART FSN

**AVERAGE NUMBER OF VEHICLES IN EACH MILEAGE INTERVAL IS THE FOLLOWING:

0 - 10,000 MILES	: 920
10,000 - 20,000 MILES	: 505
20,000 - 30,000 MILES	: 219
30,000 - 40,000 MILES	: 74
40,000 - 50,000 MILES	: 19
OVERALL	:1737

TABLE 10.10

SUMMARY OF HIGH COST PART REPLACEMENTS

FOR M51A2 5 TON DUMP TRUCK

(PARTS COSTING IN EXCESS OF $100.00)

PART FSN*	PART NOMENCLATURE	PART COST (DOLLARS)	NO. REPLACED	VEHICLE MILEAGE INTERVAL** (1000's OF MILES)				
				0-10	10-20	20-30	30-40	40-50
25107529313	WINDSHIELD ASSEMBLY	116	19	16	3	0	0	0
25109254543	FENDER, VEHICULAR	112	2	0	1	0	1	0
25200402318	PUMP ASSEMBLY	176	75	42	25	7	1	0
25200402340	PROPELLER SHAFT W/UNIVERSAL JT.	113	2	1	1	0	0	0
25200402341	PROPELLER SHAFT W/UNIVERSAL JT.	108	1	1	0	0	0	0
25202001280	AXLE	776	12	9	3	0	0	0
25206962955	TRANSFER ASSEMBLY W/FLANGES	567	40	14	20	2	3	1
25207346985	AXLE	108	8	2	4	2	0	0
25208844833	TRANSMISSION	323	1	0	0	1	0	0
25209019682	PROPELLER SHAFT W/UNIVERSAL JT.	113	18	11	4	2	1	0
25307409395	HUB, CAPS, WHEEL	109	9	4	4	1	0	0
25403017269	KIT, HOT WATER	154	16	15	1	0	0	0
25409530111	HEATER, COOLANT	150	12	6	5	1	0	0
25409603630	HEATER, VEHICULAR COOLANT	271	1	1	0	0	0	0
25906416405	WINCH ASSEMBLY	412	30	18	9	2	1	0
25907411122	WINCH ASSEMBLY	631	4	2	1	1	0	0
28050402204	CYLINDER HEAD, GASOLINE	290	29	24	4	1	0	0
28057409968	HEAD ASSEMBLY, CYLINDER	232	1	0	1	0	0	0
28150748728	CAMSHAFT	102	1	1	0	0	0	0
28150748919	HEAD GASKET SET	111	57	43	14	0	0	0
28151779239	FLY WHEEL HOUSING	139	1	1	0	0	0	0
28152395819	ENGINE AND CONTAINER	3300	432	153	168	77	25	9
28158086932	CYLINDER HEAD	135	8	8	0	0	0	0
29107595410	PUMP, FUEL	329	208	118	74	13	2	1
29108510484	TANK, FUEL, ENGINE	117	21	12	5	3	1	0
29109086319	HEAD ASSEMBLY, FUEL INJECTOR	129	2	1	1	0	0	0
29109086320	PUMP, FUEL	330	18	12	5	0	1	0
29202266545	STARTER, ENGINE, ELECTRICAL	103	296	175	87	26	7	1
29203354264	REGULATOR, ENGINE GENERATOR	125	415	248	115	42	10	0
29209747626	STARTER, ENGINE, ELECTRICAL	124	174	95	62	16	1	0
29305637235	RADIATOR, ENGINE COOLANT	108	53	53	0	0	0	0
29307375656	RADIATOR ASSEMBLY	151	135	70	39	22	4	0
29900748930	TURBO-CHARGER, COMPRESSION	295	18	10	7	1	0	0
29909679909	TURBO-CHARGER	283	24	13	10	0	1	0
40102865535	CHAIN	203	3	2	1	0	0	0
61155735653	HYDRAULIC PUMP	165	1	1	0	0	0	0
61303493685	RECTIFIER	176	1	1	0	0	0	0

*THE PARTS LISTED IN THE TABLE ARE ORDERED BY PART FSN

**AVERAGE NUMBER OF VEHICLES IN EACH MILEAGE INTERVAL IS THE FOLLOWING:

0 - 10,000 MILES : 889
10,000 - 20,000 MILES : 444
20,000 - 30,000 MILES : 173
30,000 - 40,000 MILES : 58
40,000 - 50,000 MILES : 17
OVERALL : 1581

TABLE 10.11

SUMMARY OF HIGH COST PART REPLACEMENTS
FOR M54A2 5 TON CARGO TRUCK
(PARTS COSTING IN EXCESS OF $100.00)

PART FSN*	PART NOMENCLATURE	PART COST (DOL-LARS)	NO. REPL.	VEHICLE MILEAGE INTERVAL** (1000's OF MILES)						
				0-10	10-20	20-30	30-40	40-50	50-60	60-65
25107529313	WINDSHIELD ASSEMBLY	116	6	3	3	0	0	0	0	0
25109254543	FENDER, VEHICULAR	112	1	0	0	0	0	1	0	0
25200402340	PROPELLER SHAFT W/UNIVERSAL JT	113	2	1	1	0	0	0	0	0
25200402341	PROPELLER SHAFT W/UNIVERSAL JT	108	1	1	0	0	0	0	0	0
25202001280	AXLE, REAR	776	6	2	0	1	1	2	0	0
25206926097	AXLE	738	1	1	0	0	0	0	0	0
25206962955	TRANSFER ASSEMBLY W/FLANGES	567	21	12	3	1	2	0	2	1
25207346970	DIFFERENTIAL, DRIVING AXLE, FT	383	1	1	0	0	0	0	0	0
25207346985	SHAFT	108	1	1	0	0	0	0	0	0
25209019682	PROPELLER SHAFT W/UNIVERSAL JT	113	5	3	1	1	0	0	0	0
25307409395	HUB, CAPS, WHEEL	109	1	1	0	0	0	0	0	0
25403017269	KIT, HOT WATER	154	5	5	0	0	0	0	0	0
25409530111	HEATER, COOLANT	150	7	7	0	0	0	0	0	0
25409603630	HEATER, VEHICULAR COOLANT	272	3	3	0	0	0	0	0	0
25906416405	WINCH ASSEMBLY	412	22	18	3	0	1	0	0	0
25907411122	WINCH ASSEMBLY	631	3	3	0	0	0	0	0	0
28050402204	CYLINDER HEAD, GASOLINE	290	8	6	2	0	0	0	0	0
28150748919	HEAD GASKET SET	111	26	18	8	0	0	0	0	0
28151770239	FLY WHEEL HOUSING	139	1	1	0	0	0	0	0	0
28152395819	ENGINE AND CONTAINER	3300	269	99	73	37	19	26	12	3
29107595410	PUMP, FUEL	329	127	86	33	6	1	1	0	0
29108510484	TANK, FUEL, ENGINE	117	11	5	4	2	0	0	0	0
29109086319	HEAD ASSEMBLY, FUEL INJECTOR	129	4	4	0	0	0	0	0	0
29109086320	PUMP, FUEL	330	4	4	0	0	0	0	0	0
29202260545	STARTER, ENGINE,ELECTRICAL	103	241	164	50	21	5	1	0	0
29203354264	REGULATOR, ENGINE GENERATOR	125	294	231	45	8	9	1	0	0
29209747626	STARTER, ENGINE, ELECTRICAL	124	138	114	19	5	0	0	0	0
29305637235	RADIATOR, ENGINE COOLANT	108	1	1	0	0	0	0	0	0
29307375656	RADIATOR ASSEMBLY	151	62	30	15	10	6	1	0	0
29900748930	TURBO-CHARGER, COMPRESSION	295	10	7	1	2	0	0	0	0
29909679909	TURBO-CHARGER	283	22	10	8	2	1	0	1	0

*THE PARTS LISTED IN THE TABLE ARE ORDERED BY PART FSN.
**AVERAGE NUMBER OF VEHICLES IN EACH MILEAGE INTERVAL IS THE FOLLOWING:

0 - 10,000 MILES:	553
10,000 - 20,000 MILES:	191
20,000 - 30,000 MILES:	76
30,000 - 40,000 MILES:	48
40,000 - 50,000 MILES:	44
50,000 - 60,000 MILES:	32
60,000 - 65,000 MILES:	10
OVERALL:	954

TABLE 10.12

TEN MOST FREQUENTLY REPLACED PARTS[a] FOR M52A2 5 TON TRACTOR

ORDER	VEHICLE MILEAGE INTERVAL[b] (1000's OF MILES)					
	0-10	10-20	20-30	30-40	40-50	OVERALL
1	BATTERY, (769)	BATTERY (315)	BATTERY (144)	ENGINE (61)	BATTERY (10)	BATTERY (1283)
2	LAMP, INCAND-ESCENT (601)	ENGINE (298)	ENGINE (130)	BATTERY (45)	ENGINE (8)	LAMP, INCAND-ESCENT (908)
3	BOOT (465)	PRESSURE PLATE, CLUTCH (284)	PRESSURE PLATE, CLUTCH (117)	PRESSURE PLATE, CLUTCH (37)	MIRROR ASS'Y., REAR VIEW (7)	ENGINE (757)
4	MIRROR ASS'Y., REAR VIEW (394)	CLUTCH, FRICTION (269)	CLUTCH, FRICTION (105)	CLUTCH, FRICTION (34)	SEAL, REAR SPRING (6)	BOOT (691)
5	MOTOR, WINDSHIELD WIPER (325)	LAMP, INCAND-ESCENT (202)	SLEEVE, CLUTCH RELEASE (68)	SLEEVE, CLUTCH RELEASE (24)	BEARING, SLEEVE (6)	PRESSURE PLATE, CLUTCH (576)
6	SEAL, REAR SPRING (302)	SHACKLE, LIFTING (179)	LAMP, INCAND-ESCENT (61)	MIRROR ASS'Y., REAR VIEW (19)	SEAL, PLAIN (6)	SEAL, REAR SPRING (551)
7	REGULATOR (260)	SEAL, REAR SPRING (163)	BRAKESHOE, INTERNAL (57)	CYLINDER ASS'Y., MASTER (16)	REGULATOR (3)	CLUTCH, FRICTION (547)
8	ENGINE (258)	BOOT (161)	SAFETY GLASS, (57)	CYLINDER (16)	INDICATOR, OIL PRESSURE (3)	MIRROR ASS'Y., REAR VIEW (543)
9	GASKET-STEERING MECHANISM (241)	BRAKESHOE, INTERNAL (154)	FUEL PUMP (49)	LAMP, INCAND-ESCENT (16)	PRESSURE PLATE, CLUTCH (2)	MOTOR, WINDSHIELD WIPER (514)
10	SHACKLE, LIFTING (220)	MOTOR, WINDSHIELD WIPER (151)	NOZZLE, FUEL INJECTOR (48)	BOOT (15)	CLUTCH, FRICTION (2)	BRAKESHOE, INTERNAL (429)

a. LIST EXCLUDES FILTERS AND TIRE COMPONENTS.
b. AVERAGE NUMBER OF VEHICLES IN EACH MILEAGE INTERVAL IS THE FOLLOWING:

0-10,000 MILES:	920
10,000-20,000 MILES:	505
20,000-30,000 MILES:	219
30,000-40,000 MILES:	74
40,000-50,000 MILES:	19
OVERALL:	1737

TABLE 10.13

TEN MOST FREQUENTLY REPLACED PARTS[a] FOR M51A2 5 TON DUMP TRUCK

	VEHICLE MILEAGE INTERVAL[b] (1000's OF MILES)					
ORDER	0-10	10-20	20-30	30-40	40-50	OVERALL
1	BOOT (763)	BRAKESHOE (789)	SEAL, REAR SPRING (145)	BRAKESHOE (39)	CYLINDER, WHEEL (10)	BRAKESHOE (1713)
2	BRAKESHOE (678)	SEAL, REAR SPRING (424)	BOOT (118)	SEAL, REAR SPRING (35)	SEAL, REAR SPRING (9)	BOOT (1286)
3	BATTERY (661)	BOOT (381)	CYLINDER, WHEEL (118)	CYLINDER, WHEEL (31)	ENGINE (9)	BATTERY (1133)
4	BRAKESHOE, INTERNAL (645)	BATTERY (367)	BRAKESHOE, INTERNAL (91)	ENGINE (25)	BATTERY (6)	SEAL, REAR SPRING (1113)
5	LAMP, INCAND-ESCENT (584)	CYLINDER, WHEEL (327)	BATTERY (79)	BOOT (22)	SHOCK ABSORBER (4)	BRAKESHOE, INTERNAL (1055)
6	SEAL, REAR SPRING (500)	BRAKESHOE, INTERNAL (298)	ENGINE (77)	BATTERY (20)	PUMP, HYDRAULIC STEERING (3)	LAMP, INCAND-ESCENT (817)
7	MIRROR ASS'Y., REAR VIEW (368)	CYLINDER ASS'Y., MASTER (209)	CYLINDER ASS'Y., MASTER (74)	BRAKESHOE, INTERNAL (19)	LAMP, INCAND-ESCENT (3)	CYLINDER, WHEEL (732)
8	CYLINDER ASS'Y., MASTER (338)	ENGINE (168)	LAMP, INCAND-ESCENT (61)	PRESSURE PLATE, CLUTCH ASS'Y.(16)	CYLINDER, AIR, HYDRAULIC (3)	CYLINDER ASS'Y., MASTER (637)
9	MOTOR, WINDSHIELD WIPER (316)	PRESSURE PLATE, CLUTCH (157)	MOTOR, WINDSHIELD WIPER (60)	CYLINDER, AIR, HYDRAULIC (15)	BRAKESHOE (2)	MIRROR ASS'Y., WIPER (540)
10	PIN ASS'Y., (296)	MOTOR, WINDSHIELD WIPER (156)	SAFETY GLASS (56)	CLUTCH, FRICTION (15)	BRAKESHOE, INTERNAL (2)	MIRROR ASS'Y., REAR VIEW (488)

a. LIST EXCLUDES FILTERS AND TIRE COMPONENTS.
b. AVERAGE NUMBER OF VEHICLES IN EACH MILEAGE INTERVAL IS THE FOLLOWING:

0-10,000 MILES:	889
10,000-20,000 MILES:	444
20,000-30,000 MILES:	173
30,000-40,000 MILES:	58
40,000-50,000 MILES:	17
OVERALL:	1581

TABLE 10.14

TEN MOST FREQUENTLY REPLACED PARTS[a] FOR M54A2 5 TON CARGO TRUCK

ORDER	VEHICLE MILEAGE INTERVAL[b] (1000's OF MILES)					
	0-10	10-20	20-30	30-40	40-50	OVERALL
1	BATTERY (604)	BOOT (164)	PRESSURE PLATE, CLUTCH (46)	LAMP, INCAND-ESCENT (24)	ENGINE (26)	BATTERY (820)
2	LAMP, INCAND-ESCENT (557)	BATTERY (142)	CLUTCH, FRICTION (43)	ENGINE (19)	BATTERY (11)	LAMP, INCAND-ESCENT (746)
3	BOOT (414)	LAMP, INCAND-ESCENT (119)	LAMP, INCAND-ESCENT (39)	BRAKESHOE, INTERNAL (17)	LAMP, INCAND-ESCENT (7)	BOOT (618)
4	GASKET, STEERING MECHANISM (327)	BRAKESHOE (111)	BRAKESHOE, INTERNAL (39)	CLUTCH, FRICTION (16)	BOOT (4)	BRAKESHOE, INTERNAL (474)
5	BRAKESHOE, INTERNAL (315)	BRAKESHOE, INTERNAL (101)	ENGINE (37)	BATTERY (16)	PRESSURE PLATE, CLUTCH (4)	SEAL, REAR SPRING (368)
6	MIRROR ASS'Y., REAR VIEW (292)	CYLINDER, WHEEL (91)	BOOT (26)	PRESSURE PLATE, CLUTCH (14)	CLUTCH, FRICTION (4)	CYLINDER ASS'Y., MASTER (349)
7	SEAL, REAR SPRING (252)	SEAL, REAR SPRING (88)	MOTOR, WINDSHIELD WIPER (20)	SEAL, REAR SPRING (12)	HEADLIGHT (4)	MIRROR ASS'Y., REAR VIEW (342)
8	MOTOR, WINDSHIELD WIPER (243)	CYLINDER ASS'Y., MASTER (85)	CYLINDER ASS'Y., MASTER (19)	BOOT (10)	CYLINDER, WHEEL (3)	GASKET, STEERING MECHANISM (338)
9	REGULATOR (232)	ENGINE (73)	SAFETY GLASS, LAMINATED (16)	REGULATOR (9)	SAFETY GLASS, LAMINATED (3)	MOTOR, WINDSHIELD WIPER (335)
10	SHACKLE, LIFTING (215)	MOTOR, WINDSHIELD WIPER (62)	REGULATOR (16)	SHACKLE, LIFTING (9)	LOCK, DOOR (3)	BRAKESHOE (329)

a. LIST EXCLUDES FILTERS AND TIRE COMPONENTS.
b. AVERAGE NUMBER OF VEHICLES IN EACH MILEAGE INTERVAL IS THE FOLLOWING:

0-10,000 MILES:	553
10,000-20,000 MILES:	191
20,000-30,000 MILES:	76
30,000-40,000 MILES:	48
40,000-50,000 MILES:	44
OVERALL:	912

to near 40¢ per mile at 50,000 miles.

During the 50,000 miles of usage, the average tractor will have 37.6 unscheduled maintenance actions (UMA's) with the mean miles between UMA's of 1330 miles. When the tractor is in the maintenance shop for a UMA, on the average 2.3 different parts will be repaired, replaced or adjusted. During the average UMA 2.6 man-hours will be expended for each part worked on and thus a total of 5.9 man-hours will be expended during an average UMA.

For each 1000 miles of usage, an average of 9.2 man-hours of maintenance (scheduled and unscheduled) are required. Of these man-hours, 4.2 man-hours are for unscheduled maintenance and 5.0 man-hours are for scheduled maintenance. For every hour of truck operation (assuming an average speed of 20 mph), the truck on the average requires .18 man-hours of maintenance.

During 50,000 miles of usage, the major components of the vehicle will have exhibited the following: (1) there is a 100% chance of an engine being replaced (it is expected that the average truck will sustain 3.1 engine replacements over this mileage interval), (2) there is a 2% chance of an axle being replaced, (3) there is a 1% chance of a differential being replaced, and (4) there is a 23% chance of the transfer case being replaced.

From an availability and reliability standpoint, there is a .92 probability that the average tractor will not be undergoing active repair due to an unscheduled maintenance action (UMA) at any point in time and a .91 probability that the tractor will complete a random 75 miles without a UMA. It should be noted that a UMA is not necessarily a mission abort failure.

11.2 M51A2 Dump Truck.

The average M51A2 5 Ton Dump Truck during the initial 50,000 miles of usage will sustain a total maintenance cost (for both scheduled and unscheduled maintenance) of $12,600 or an average maintenance cost of 25¢ per mile. The average maintenance cost will be noted to be increasing during the initial 50,000 miles from 19¢ per mile at 1000 miles to 31¢ per mile at 50,000 miles.

During the 50,000 miles of usage, the average dump truck will have 48.8 UMA's with the mean miles between UMA's of 1025 miles. When the dump truck is in the maintenance shop for a UMA, on the average 1.8 different parts will be repaired, replaced or adjusted. During the average UMA 2.2 man-hours will be expended for each part worked on and thus a total of 3.9 man-hours will be expended during an average UMA.

For each 1000 miles of usage, an average of 7.7 man-hours of maintenance (scheduled and unscheduled) are required. Of these man-hours, 3.9 man-hours are for scheduled maintenance and 3.8 man-hours are for unscheduled maintenance. For every hour of truck operation (assuming an average speed of 20 mph), the dump truck on the average requires .15 man-hours of maintenance.

During 50,000 miles of usage, the major components of the vehicle will have exhibited the following: (1) there is a 100% chance of an engine being replaced (it is expected that the average dump truck will sustain 2.1 engine replacements over this mileage interval), (2) there is a 5% chance of an axle being replaced, (3) there is essentially no chance of a differential being replaced and, (4) there is a 21% chance of a transfer case being replaced.

From an availability and reliability standpoint, there is a .93 probability that the average dump truck will not be undergoing active repair due to an unscheduled maintenance action (UMA) at any point in time and a .91 probability that the dump truck will complete a random 75 miles without a UMA.

11.3 M54A2 Cargo Truck.

The average M54A2 5 Ton Cargo Truck during the initial 65,000 miles of usage will sustain a total maintenance cost (for both scheduled and unscheduled maintenance) of $16,200 or an average maintenance cost of 25¢ per mile. The average maintenance cost will be noted to be increasing during the initial 65,000 miles from 20¢ per mile at 1000 miles to 29¢ per mile at 65,000 miles.

During the 65,000 miles of usage, the average cargo truck will have 56.0 UMA's with the mean miles between UMA's of 1161 miles. When the cargo truck is in the maintenance shop for a UMA, on the average 1.9 different parts will be repaired, replaced or adjusted. During the average UMA 2.7 man-hours will be expended for each part worked on and thus a total of 5.1 man-hours will be expended during an average UMA.

For each 1000 miles of usage, an average of 9.5 man-hours of maintenance (scheduled and unscheduled) are required. Of these man-hours, 5.3 man-hours are for scheduled maintenance and 4.2 man-hours are for unscheduled maintenance. For every hour of truck operation (assuming an average speed of 20 mph), the cargo truck on the average requires .19 man-hours of maintenance.

During 65,000 miles of usage, the major components of the vehicle will have exhibited the following: (1) there is a 100% chance of an engine being replaced (it is expected that the average cargo truck will sustain 2.7 engine replacements over this mileage interval), (2) there is a 10% chance of an axle being replaced, (3) there is essentially no chance of a differential being replaced and, (4) there is a 16% chance of a transfer case being replaced.

From an availability and reliability standpoint, there is a .92 probability that the average cargo truck will not be undergoing active repair due to an unscheduled maintenance action (UMA) at any point in time and a .92 probability that the cargo truck will complete a random 75 miles without a UMA.

II. COMPARISON OF STUDY RESULTS WITH OTHER DATA SOURCES

In the course of this study, other data sources were sought out in order to establish if any verification of the results of this study could be obtained from other data sources. In this connection, visits were made to commercial trucking firms to inquire about the life of their comparable vehicles, data from REFORGER exercises were reviewed, the AMC Materiel Readiness Report was examined and discussions were held with various maintenance experienced military personnel on the performance and maintenance problems associated with the M39A2 5 ton trucks.

In order to obtain information on the life of commercial vehicles comparable to the Army's 5 ton truck, visits were made to United Parcel Service (25,000 truck fleet) and to the Branch Motor Express Truck Company (2,500 truck fleet). It was pointed out to these firms that life information was not desired on trucks that travel in excess of a 100,000 miles a year on major interstate highways as the Army military vehicles do not travel these distances but on shorter haul vehicles that accumulate substantially less mileage each year. Both firms indicated that they do have vehicles that accumulate only up to 10,000 miles per year (mainly for intracity usage) and that the life of these vehicles varied from 50,000 to 70,000 miles. It was indicated that during these mileage intervals the engines in particular required replacement. These life indications, thus are consistent with the 60,000 mile life indicated by this study for the 5 ton truck.

During the preparation of this report, the European theatre was visited to obtain information on the performance and reliability of vehicle systems being utilized in REFORGER exercises. In this connection, some summary data for the 5 ton truck was obtained for the previous REFORGER exercises (1973) which may be compared to the results obtained from this study. In particular, a list of the most frequently replaced parts that occurred during REFORGER was obtained and was noted to be similar to the most frequently replaced parts shown in this report. For example, during REFORGER the battery, shackle, lights and C.V. boot were among the most frequently replaced components of the 5 ton truck. It is noted that all of these parts also appear on the 10 most frequently replaced list derived from this study.

In addition to the above, it was also decided to discuss the results of this study with experienced military personnel to determine how the results of this study relates to their own personnal experiences.

In this connection, discussions were held with various maintenance units, transportation groups and with a number of individual maintenance experienced personnel. Primarily discussed were those parts in the 5 ton truck that in their experience were causing the most problems. The components mentioned were all noted to be parts that this study shows were among the most frequently replaced components. For example, the battery, engine and regulator were most often mentioned. The battery, however, was the most constantly mentioned component. When discussing the battery some very strong comments were made concerning the Army's usage of batteries. It was pointed out that the location of the battery, the number of interconnecting cables and the constant checking of the battery were causing a substantial number of battery failures. It was noted that the batteries in the 5 ton truck (most frequently replaced item) and in the 2 1/2 ton truck (third most frequently replaced item) are mounted in a rack which has to be pulled out in order to check fluid levels. As this procedure occurs frequently the battery is constantly being pulled out and pushed in which ultimately results in a loose connection between the battery cables and the battery terminals. It was pointed out that even a slightly loose connection will cause an electrical arc to develop across the terminal and cable when starting the vehicles which burns out the terminal and terminates the life of the battery. It was further pointed out that the Army's "spit and polish" emphasis was also causing battery failures. For example, when even a slight amount of corrosion is detected on the battery, the battery must be removed and the corrosion cleaned off. When replacing the batteries (two batteries in each truck), the cables are sometimes placed on the wrong terminals with the resultant battery destruction. It should be noted that at the current time, the Army is procuring 300,000 batteries a year at a cost of nearly $10 million (reference TACOM Mobility System Laboratory Annual Posture Report, 1974). A solution to the battery replacement problem appears threefold: (1) substantially reduce the number of battery checks (2) remove the battery to clean off corrosion only when the corrosion is substantial and is considered to have a degrading effect on the life of the battery and (3) develop a single 24-volt battery which will have less cables than the current two 12-volt batteries (this will reduce the chance of incorrectly connecting the battery cables). It is mentioned that TACOM does have under development a 24-volt battery which will replace the two 12-volt batteries which in turn will eliminate some of the cables presently used in military trucks. However, this development is indicated to be at least a year away. This development, however, will only satisfy item 3 above.

In summary, in comparing the results of this study to other data sources, both hard data and personal military experience information, good agreement of the study results with the data from the other sources was noted.

APPENDIX

General Weighted Multiple Linear Regression

Under this analysis the data are considered to consist of k ordered (r+2) - tuples $(y_1,n_1,x_{11},x_{12},x_{13},\ldots,x_{1r})$, $(y_2,n_2,x_{21},x_{22},x_{23},\ldots,x_{2r}),\ldots,(y_k,n_k,x_{k1},x_{k2},x_{k3},\ldots,x_{kr})$ where y_i is the i-th observation of the dependent variable (the variable to be predicted), n_i is the sample size for the i-th observation, and x_{ij} is the i-th observation for the j-th independent variable (variables to be used for future predictions) $i=1,2,3,\ldots,k$ and $j=1,2,3,\ldots,r$. It is assumed that the dependent variable y_i can be expressed as a linear function of the x_{ij} plus a random variable ε_i. Thus, the model is

$$y_i = \beta_o+x_{i1}\beta_1+x_{i2}\beta_2+\ldots+x_{ir}\beta_r+\varepsilon_i.$$

However, since the precision of the i-th observation is dependent upon its sample size n_i, a transformation of the data is necessary to remove this dependency and obtain equality of variances. The model then becomes

$$y_i^* = x_{io}^*\beta_o+x_{i1}^*\beta_1+x_{i2}^*\beta_2+\ldots+x_{ir}^*\beta_r+e_i$$

where $y_i^* = \sqrt{n_i}y_i$

$x_{io}^* = \sqrt{n_i}$

$x_{ij}^* = \sqrt{n_i}x_{ij}$

or in matrix notation

$$\tilde{y} = \tilde{X}\tilde{\beta} + \tilde{e} \qquad (1)$$

where

$$\tilde{y} = \begin{bmatrix} y_1^* \\ y_2^* \\ \cdot \\ \cdot \\ \cdot \\ y_k^* \end{bmatrix} \qquad \tilde{\beta} = \begin{bmatrix} \beta_o \\ \beta_1 \\ \cdot \\ \cdot \\ \cdot \\ \beta_r \end{bmatrix} \qquad \tilde{e} = \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ e_k \end{bmatrix}$$

$$\tilde{X} = \begin{bmatrix} x_{10}^* & x_{11}^* & x_{12}^* & \cdots & x_{1r}^* \\ x_{20}^* & x_{21}^* & x_{22}^* & \cdots & x_{2r}^* \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ x_{ko}^* & x_{k1}^* & x_{k2}^* & \cdots & x_{kr}^* \end{bmatrix}$$

The e_i are assumed to be uncorrelated ($E(e_i e_j) = 0$ for $i \neq j$) and normally distributed random variables with mean zero and variance σ^2. The independent variables are assumed to be controlled or measured accurately and are therefore relatively free of error. The unknown parameters in the model $\beta_0, \beta_1, \beta_2, \ldots, \beta_r$ are estimated by the method of least squares. Let $\tilde{b} = (b_o, b_1, b_2, \ldots, b_r)^T$ be the column vector of the required estimates, then these estimates have the property that they minimize the expression

$$S = \sum_{i=1}^{k} (y_i^* - \sum_{j=0}^{r} x_{ij}^* b_j)^2$$

or in matrix notation

$$S = || \tilde{y} - \tilde{X}\tilde{b} ||^2 \qquad (2)$$

where $||v||$ denotes the norm of the vector v.

In order to find the required estimates of β_2 ($\nu = 0,1,2,\ldots,r$), we set the partial derivates of S with respect to b_ν equal to zero.

$$\frac{\partial S}{\partial b_\nu} = -2\sum_{i=1}^{k}(y_i^* - \sum_{j=0}^{r} x_{ij}^* b_j) x_{i\nu} = 0$$

or

$$\sum_{i=1}^{k}\sum_{j=0}^{r} x_{i\nu}^* x_{ij}^* b_j = \sum_{i=1}^{k} x_{i\nu}^* y_i^* .$$

These r+1 simultaneous equations corresponding to $\nu = 0,1,2,\ldots.r$ are called the normal equations in regression analysis. In matrix notation the normal equations may be written

$$\tilde{X}^T\tilde{X}\tilde{b} = \tilde{X}^T\tilde{y} \tag{3}$$

where $\tilde{X}^T$ is the transpose of $\tilde{X}$.

$$\text{Let } (\tilde{X}^T\tilde{X})^{-1} = \begin{bmatrix} c_{00} & c_{01} & c_{02} & \cdots & c_{0r} \\ c_{10} & c_{11} & c_{12} & \cdots & c_{1r} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ c_{r0} & c_{r1} & c_{r2} & \cdots & c_{rr} \end{bmatrix}$$

be the inverse of the matrix $\tilde{X}^T\tilde{X}$. Then the required estimate of $\tilde{\beta}$ is given by

$$\tilde{b} = \left(\tilde{X}^T\tilde{X}\right)^{-1}\tilde{X}^T\tilde{y} \tag{4}$$

Since the b_j ($j = 0,1,2,\ldots,r$) are only estimates of the unknown constants β_j, computed from the observed data, they are subject to variation if a new set of data became available and the same procedure was applied to this data. Then the b_j are random variables and it can be shown that the mean or expected value of b_j is equal to β_j, i.e., $E(b_j) = \beta_j$. Estimates of the standard deviation of b_j are obtained as follows:

$$s_{b_o} = s\sqrt{c_{00}} \quad (5)$$

$$s_{b_1} = s\sqrt{c_{11}}$$

$$\vdots$$

$$s_{b_r} = s\sqrt{c_{rr}}$$

where

$$s = \sqrt{\frac{1}{k-r-1}\,[\tilde{y}^T\tilde{y}-\tilde{b}\tilde{X}^T\tilde{y}]} \quad (6)$$

Under the assumptions made for the regression model, $(b_j-\beta_j)/s_{b_j}$ has the Student's t-distribution with k-r-1 degrees of freedom. This fact can be used to construct a confidence interval estimate of the unknown parameter β_j. Then

$$b_j \pm t_{1-\frac{\alpha}{2},\,k-r-1}\, s_{b_j} \quad (7)$$

is a $(1-\alpha)$ 100% confidence interval for β_j, where $t_{1-\frac{\alpha}{2},\,k-r-1}$ is the $1-\frac{\alpha}{2}$ percentile of the Student's t-distribution with k-r-1 degrees of freedom[1]. The interpretation of this interval is that if intervals of this type are repeatedly constructed following this procedure, $(1-\alpha)$ 100% of these intervals will contain the population parameter β_j being estimated. This confidence interval can also be used to test the hypothesis that $\beta_j = \beta^0$ where β^0 is a given constant. If the interval obtained from Equation (7) contains β^0, then we would accept the hypothesis H_0: $\beta_j = \beta^0$. If the interval does not contain β^0, then we would reject this hypothesis. This test criterion has the property that if β_j actually equals β^0 then the probability that the hypothesis H_0: $\beta_j = \beta^0$ will be rejected is equal to α (assuming a $(1-\alpha)$ 100% confidence interval) and the probability that H: $\beta_j = \beta^0$ will be rejected if β_j equals any other given number can be computed using the non-central t-distribution[2]. An important special case is that of the null hypothesis, i.e., $H_0 = \beta_j = 0$. If based on a test of significance H_0: $\beta_j = 0$ is accepted, β_j might be considered to be dropped from the model since it does not appear to be making a significant contribution to the estimation of the dependent variable.

Under the original model, the mean or expected value of y for a given value of $(x_1, x_2, \ldots, x_r)$ is

$$E(y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_r x_r$$

where β_0, β_1, $\beta_2, \ldots, \beta_r$ are the unknown parameters to be estimated. Thus

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_r x_r \tag{8}$$

gives an estimate of the mean value of y for a given value of $(x_1, x_2, \ldots, x_r)$.

Assumptions for Economic Replacement Policy

The methodology utilized in the cost analysis assumes the existence of a relative equality of certain measurable parameters. Specifically, it is assumed that an equality of economic benefits derived from performance parameters exists throughout the economic or useful life of the vehicle. Thus, the useful life of the vehicle is determined by minimizing a cost function with respect to mileage rather than maximizing a benefit cost function. Also, since there exists a functional relationship between factor or investment price and amount or quantity demanded, there is an implied assumption of relative equality of demand for the item over the duration of the replacement interval. This would ensure that both fixed and variable cost factors would be of a continuous nature over the economic life. Finally, it should be noted that this methodology is applicable for continuous replacement with vehicles having similar costs or variable and fixed cost factors that remain in proportion. Proportionate changes of these cost factors over yearly intervals will shift the cost axis but will not affect the mileage criterion. It should be further noted that the cost analysis described above does not consider the options associated with replacement of an M39A2 with an overhauled vehicle, since variable and fixed costs of an overhauled vehicle are still being determined (Sample Data Collection Program). The analysis will then depend on a long-run cost comparison of overhaul vehicle replacement versus new vehicle replacement.

REFERENCES

1. Scheffe, Henry, The Analysis of Variance, John Wiley and Sons, Inc., New York, 1959.

2. Resnikoff and Lieberman, Tables of the Non-Central t-Distribution, Stanford University Press, Stanford, California, 1957.

3. Draper and Smith, Applied Regression Analysis, John Wiley and Sons, Inc., New York, 1966.

4. Stonier and Hague, Economic Theory, John Wiley and Sons, Inc., New York, 1953.

5. Grawoig, Dennis E., Decision Mathematics, McGraw-Hill Book Company, New York, 1967.

6. Crow, Larry H., Weibull Reliability Procedures For Complex, Repairable Systems, AMSAA Technical Report No. 81, to be published.

7. Bell, Raymond; Mioduski, Robert E.; Belbot, Edward F.; Rosati, Robert A.; Crow, Larry H., Vehicle Average Useful Life Study for Truck, Cargo: 2 1/2 Ton, 6x6, M35A2, AMSAA Technical Memorandum No. 163, October 1973.

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